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CONTENT

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Assessment of labor conditions class by the intensity of heat treatment by the method of diagrams when changing the layout of technological equipment

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Introduction. Failure to comply with the requirements for the technological microclimate can lead to the development of occupational diseases and accidents. Therefore, in the general system of measures that ensure normal working conditions, one of the most important tasks is to reduce heat emissions.
Problem Statement. The paper studies the thermoradiation mode of workplaces. For this purpose, a scientific method based on the construction of radiation diagrams is used. The irradiation field of an object is based on the radiation diagrams of various sources that affect the working space.
Theoretical Part. Diagrams are used to express the quantitative parameters and boundaries of the distribution of radiant flows in the total field of irradiation of the workplace. Diagrams are built for different operating modes and operations based on theoretical calculations or real measurements. The method of diagrams is considered on the example of the cementation section of the foundry. The result of replanning, i.e. changing the location of the furnaces installed in the room, is shown.
Conclusion. The study of the intensity of thermal irradiation of the workplace by the method of diagrams showed that changing the layout of production equipment, as well as protection by distance, helps to reduce heat radiation and thus ensure compliance with sanitary and hygienic standards adopted for production facilities.

Keywords: thermal irradiation, thermal shop, modeling, thermal irradiation diagrams.

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Introduction. The worker's body is significantly affected by the conditions of the production room, which affect the heat exchange of the person and the environment. In metallurgy, the microclimate in the workplace is determined by the speed of air movement, the intensity of thermal radiation from equipment and surfaces, and relative humidity.

Failure to comply with the requirements of the technological microclimate can lead to the development of occupational diseases and accidents. Therefore, in the general system of measures ensuring normal working conditions, one of the most important tasks is the reduction of heat emissions.

The greatest impact on the human body has the intensity of the radiation flow. It depends on a number of factors, including:

— location of the equipment,
— size of the radiating surface,
— duration of exposure,
— distance to the radiation source,
— angle of incidence of the rays.

Problem statement. The authors investigate the heat radiation mode of workplaces. For this purpose, a scientific method based on the construction of radiation distribution diagrams is used. The radiation field of an object is based on the radiation fields of various sources that affect the workplace.

Theoretical part

Method of distribution diagram of exposure. Distribution diagram — a flat vector diagram of the location of irradiation in the space surrounding the source (radiation distribution diagram), or on the surface of the object (exposure distribution diagram). Distribution diagrams are built in a vertical or horizontal plane. For a technically sound solution for thermal protection of the workplace, it is necessary to know the type, amount of irradiation, spectral composition, as well as the direction of the prevailing radiant flow, in order to correctly determine the installation location and the size of the screen or the curtain. A visual picture of the irradiation field is shown by the exposure distribution diagram, which represents the distribution of irradiations that occur on the surface of an object when exposed to various heat sources. So, using distribution diagrams, you can express the quantitative parameters and boundaries of the distribution

of radiant fluxes in the total irradiation field of the workplace. When constructing distribution diagrams of an open space, the worker's chest is taken as the center. Distribution diagrams are constructed for different operating modes and operations based on theoretical calculations or natural measurements of irradiance values [1].

Let us consider this method on the example of a foundry cementation site (Fig. 1).

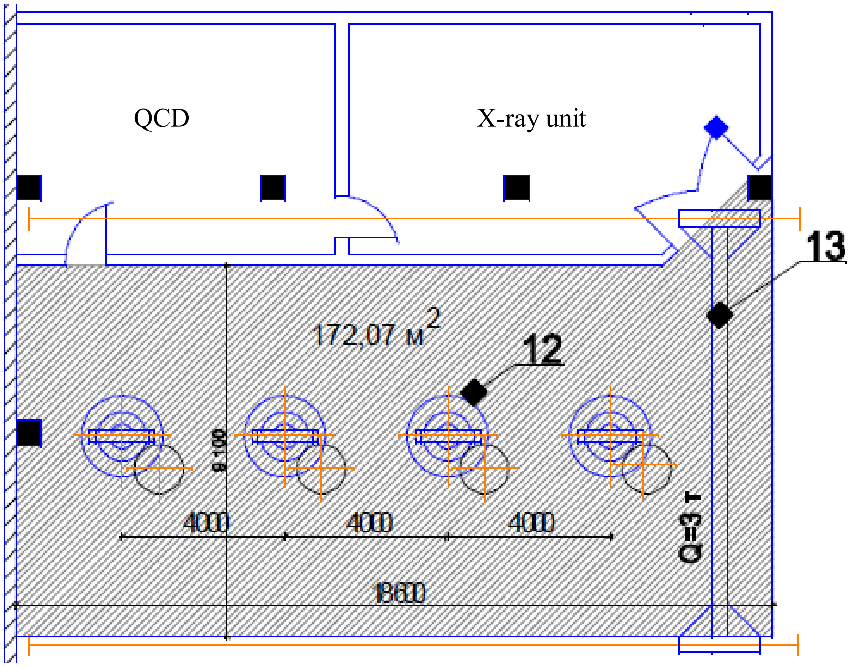

Fig. 1. Plan of the foundry

On this territory there are unfavorable conditions due to the large number of electric furnaces of the type Ts-105A, epy workers are exposed to infrared radiation from almost all sides.

To determine the thermal irradiation of a person using the distribution diagram method, it is necessary to know the exact dimensions of the shop, equipment, and the distance from the radiation source to the workplace [2]. Fig. 2 shows a diagram of the construction of the exposure distribution diagram for operators who are constantly engaged in hot work at the furnaces.

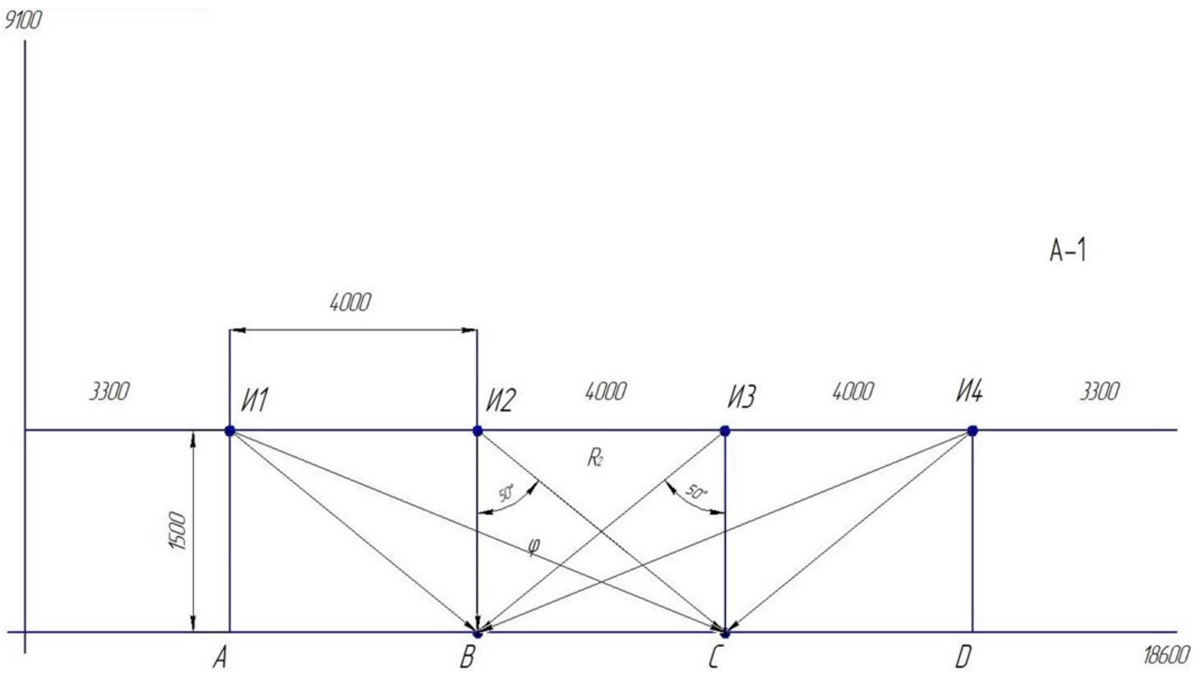

Fig. 2. Diagram for calculating the exposure distribution diagram of the furnace operator

Points A, B, C, D — four positions of the casters serving the furnace and realizing the technological process of carburizing the shanks. I1, I2, I3, I4— electric furnaces located at a close distance relative to each other. The temperature of each varies from 700 °C to 910 °C. Heat treatment mode: heating of the shanks and exposure to the carburizing medium.

Radiation intensity of the source that affects the employee:

$$E_0 = \varepsilon C_0 \left(\frac{T}{100}\right)^4, \quad (1)$$

whereε — the emissivity factor; C_0— the radiation coefficient of a black body radiator, W/(m^2·K) (C_o= 5,67); *T*— the temperature of the radiation source, K.

The radiation intensity when the cover of all four sources is open is equal to $E_0 = 69710{,}2$ W/m^2, when the cover is closed $E_0 = 1097{,}5$ W/m^2.

Thermal calculation of radiation acting on employees in four positions, W/m^2:

$$E_1 = \frac{E_0}{\pi r_1^2 cos\varphi_1}. \quad (2)$$

According to formula (2), we will combine all the data obtained in the calculation in table 1 and determine the class of working conditions for the operator of thermal equipment.

Table 1

Classes of working conditions depending on the thermal radiation of furnaces, W/m^2

	A	B	C	D
Oven windows I1,I2,I3,I4 are open	13478,2	14846,5	14846,5	13478,2
Classofworkingconditions	4	4	4	4
Oven windows I1,I2,I3,I4 are closed	212,2	233,7	233,7	212,2
Classofworkingconditions	3,1	3,1	3,1	3,1
Oven window I1 is open,I2,I3,I4 are closed	9923,9	2197,4	1207,4	829,1
Classofworkingconditions	4	3,3	3,1	3,1
Oven window I2 is open,I1,I3,I4 are closed	2175,9	9945,4	2197,4	1185,9
Classofworkingconditions	3,3	4	3,3	3,1
Oven window I3 is open,I1,I2,I4 are closed	1185,9	2197,4	9945,4	2175,9
Classofworkingconditions	3,1	3,3	4	3,3
Oven window I4 is open,I1,I2,I3 are closed	829,1	1207,4	2197,4	9923,9
Classofworkingconditions	3,1	3,1	3,3	4

As follows from the results of calculations, the sanitary and hygienic standard for the level of irradiation of open workplaces of the caster 140 W/m^2 is significantly exceeded (by 6-71 times)[1].

Improper placement of furnaces can create adverse situations in which workers are exposed to infrared radiation from almost all sides. So-called heat pockets are formed and there are conditions under which the norms of thermal insulation of the body of workers are violated.

According to the distribution diagrams method described above, we will check how effective the redevelopment of the production premises is, whether it helps to reduce heat dissipation and thereby improve the class of working conditions [3].

Using the principle of "protection by distance", we have calculated mathematically according to the scheme of the shop, at what maximum possible distance from each other the electric furnaces I1, I2, I3, I4 and the foundry workers should be. The diagram of irradiation of workers during the re-planning of equipment in the shop is shown in Fig. 3.

[1]Gigienicheskietrebovaniya k mikroklimatuproizvodstvennykhpomeshchenii.SanitarnyepravilainormySanPiN 2.2.4.548-96 [Hygienic requirements for the microclimate of industrial premises.Sanitary rules and regulations SanPiN 2.2.4.548-96].Goskomsanepidnadzor of Russia.Rossiiskayagazetaot 1stOctober 1996. Available from: https://rg.ru/2010/07/15/sanpin548-dok.html.

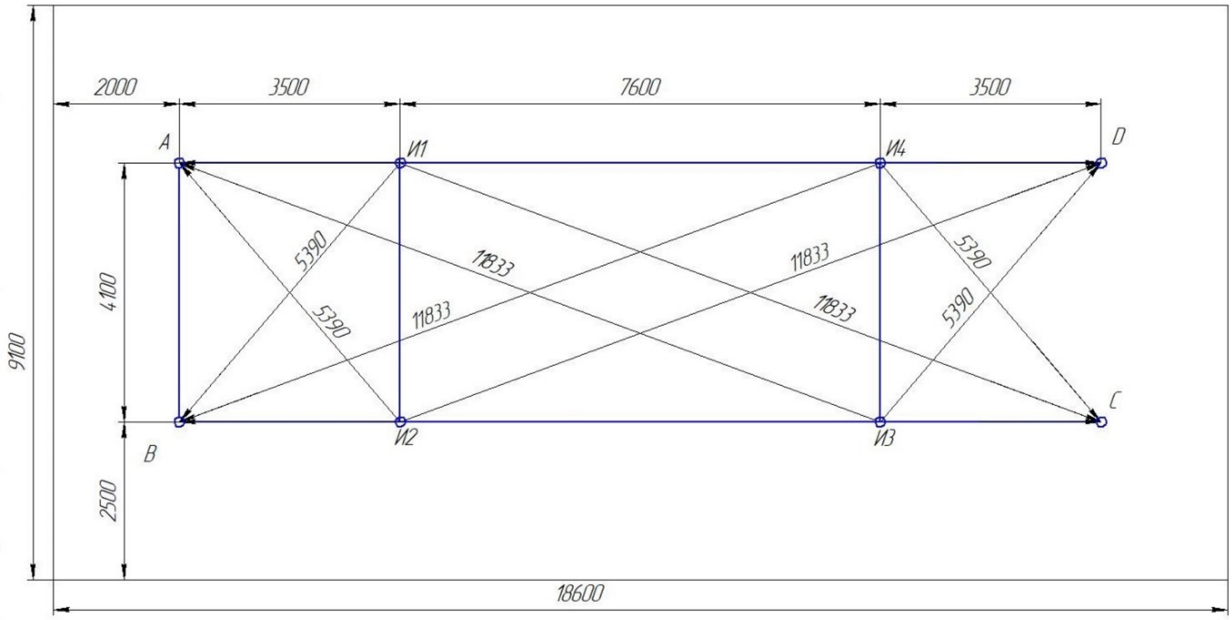

Fig. 3. Scheme for calculating the exposure distribution diagrams of workers when moving equipment in the foundry

Having made similar calculations for the shop with a new layout of equipment and working places change, in table 2 we will summarize the results of calculations of heat radiance of electric furnace operators.

Table 2

Classes of working conditions depending on the thermal radiation of furnaces after the redevelopment of the shop, W/m^2

	A	B	C	D
Oven windows I1,I2,I3,I4 are open	3431,3	3431,3	3431,3	3431,3
Classofworkingconditions	4	4	4	4
Oven windows I1,I2,I3,I4 are closed	53,9	53,9	53,9	53,9
Classofworkingconditions	2	2	2	2
Oven window I1 is open,I2,I3,I4 are closed	1837,7	1032,2	491,8	231,3
Classofworkingconditions	3,2	3,1	3,1	3,1
Oven window I2 is open,I1,I3,I4 are closed	1032,2	1837,7	231,3	491,8
Classofworkingconditions	3,1	3,2	3,1	3,1
Oven window I3 is open,I1,I2,I4 are closed	491,8	231,3	1837,7	1032,2
Classofworkingconditions	3,1	3,1	3,2	3,1
Oven window I4 is open,I1,I2,I3 are closed	231,3	491,8	1032,2	1837,7
Classofworkingconditions	3,1	3,1	3,1	3,2

When changing the location of the equipment, the intensity of thermal irradiation of workers significantly decreased. The sanitary and hygienic standard for the level of irradiation of open workplaces of operators of electric stoves 140 W/m^2 was exceeded by 1,6-13 times.

Changes in the classes of working conditions of employees before and after the redevelopment are presented in the form of a diagram (Fig. 4). Four conditions were related to the 4th class. After the transformation, such dangerous conditions are not recorded at the enterprise. Six conditions were in class 3.2 and were also completely eliminated. Accordingly, these ten conditions have become less dangerous. Now they belong to class 3.1, as it can be clearly seen in the diagram.

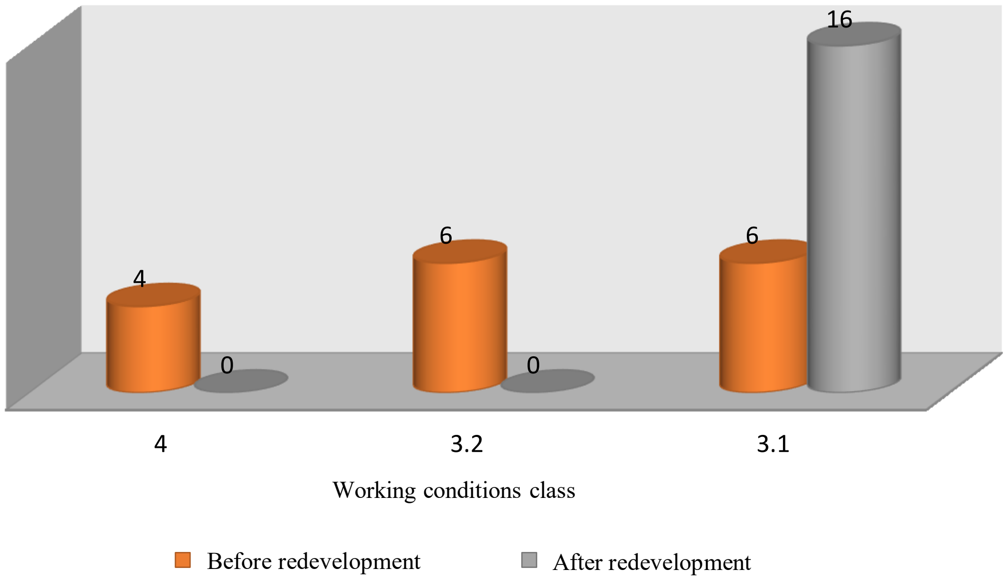

Fig. 4. Reduction of the hazard level of working conditions after the redevelopment of the shop

Thus, setting the optimal distance between the furnaces allowed us to reduce the class of working conditions to the 1st degree of harm (with the initial indicators of dangerous and harmful conditions of the 2nd degree [4]).

Conclusion. The operator of the electric furnace works in harmful conditions. One of the main factors that negatively affect the employee is the heating microclimate. Study of the intensity of thermal radiation of the workplace by distribution diagram method showed that alterations to industrial premises, as well as the protection distance will help reduce heat radiation and thus to ensure the compliance with sanitary and hygienic standards developed for industrial premises.

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Analysis of conflict points, conflict situations and calculation of traffic density on a given section of the road network

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Introduction. The paper considers traffic in Kombaynostroiteley square in Rostov-on-Don. The necessity and possibility of organizational improvement of the situation on this road network section is noted. Taking into account the active development of the city in particular and the Rostov agglomeration in general, the results of the study will be relevant in the development of the control system and the street network.
Problem Statement. It is necessary to record and evaluate the main parameters of road and pedestrian traffic on the considered section of the road network in order to further improve the organization of traffic.
Theoretical Part. Conflict points and conflict situations on a given section of the road network are analyzed. For three days, traffic and pedestrians density during rush hours was recorded. The corresponding average-per-day indicator is calculated. Traffic flow composition from the point of view of types of transport is described. The data is visualized as charts and cartograms.
Conclusion. Traffic density and composition determines its speed, so they are taken into account in the design of traffic control systems, the development of the street network and the development of the general plan of the city. For the section under consideration, the rush hours are 10 a.m. and 5 p.m. The intensity increases up to 10 a.m., changes slightly from 11 a.m. to 7 p.m., and then decreases.

Keywords: traffic, conflict points, average-per-day traffic density, road network.

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Introduction. The study of car traffic on Kombaynostroiteley square near the Rostselmash cultural centre in Rostov-on-Don has showed that the traffic flow at this interchange can be optimized. For this purpose, it is necessary to assess the intensity of traffic, determine the conflict points of the site and, based on the data obtained, offer options for improving the situation, reducing accidents. The results of the study will be relevant in the design of the development of the regulatory system, the street network and the general plan of the city.

Problem statement. As part of this work, it is planned to record and evaluate the main parameters of car and pedestrian traffic on the considered section of the road network in order to further improve the organization of traffic.

Theoretical part. Analysis of conflict points and conflict situations on a given section of the road network. The paper considers the roundabout on Kombaynostroiteley square in Rostov-on-Don. The turning circle is located at the intersection of Selmash Ave., 1stKonnoyArmii St. and Selivanov St.

According to the five-point system, the conflict points available here are evaluated as follows (Fig. 1):

— the intersection (5 points),
— the merging (3 points),
— thedivision (1 point).

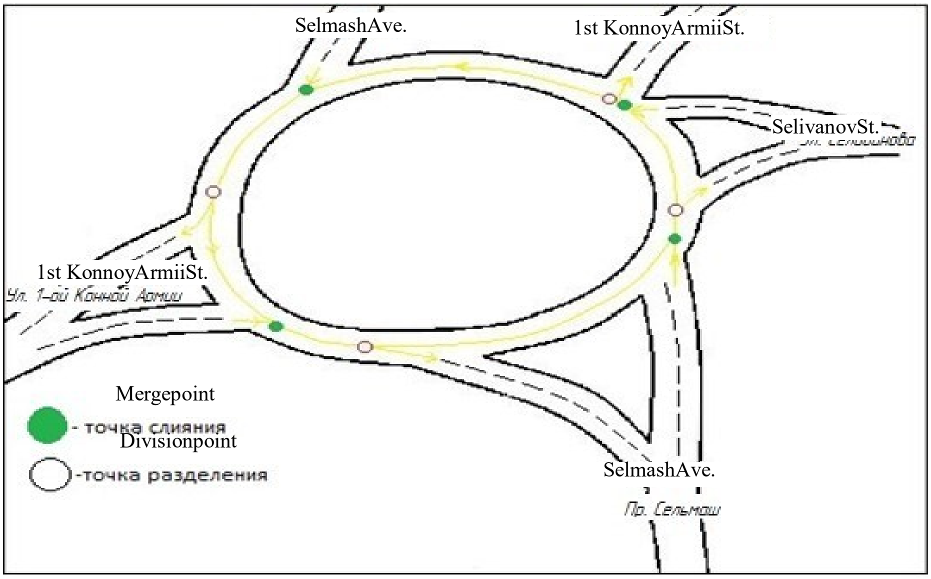

Fig. 1. Conflict points at a roundabout
(Kombaynostroiteley square, Rostov-on-Don)

We use the intersection complexity formula [1]

$$m = n_p + 3n_c + 5n_n ,$$

wheren_p — the number of division points, n_c — the number of merge points, $n_\text{п}$ — the number of intersection points.

The object is not an intersection, but a ring, so there are no intersection points here. Therefore, $5n_n$ is equal to zero:

$$m = n_p + 3n_c = 6 + 24 = 30 .$$

In our case $m < 40$.This means that the node is simple.

The number of conflict points is measured by the number of lanes and permitted vehicle directions [2].

After calculating the conditional index m of intersection complexity, you need to find out which category this intersection belongs to[1]. This is the basis for measures to improve the organization of road traffic in the area under consideration [3].

Conflict points are conditionally assigned hazard points on a ten-point system (table. 1).

Table 1

Hazard points for conflict points at a transport interchange

Conflict point	Assessment, score
Segregating	1
Merging	2
Intersection at an angle, deg:	
30	3
60	4
90	6
120	7
150	8
180 (oncoming traffic)	10

[1]Recommendations for ensuring safety on the roads. Road industrial methodical document 218.1.052-2002 [Rekomendatsii po obespecheniyu bezopasnosti dvizheniya na avtomobil'nykh dorogakh. ODM 218.1.052-2002]. Moscow Automobile And Road Construction State Technical University (MADI), FSUE "Rosdornii", ITS VolgGASA; Department of operation and safety of highways of the Federal Rroad Agency. Techexpert: Available from: http://docs.cntd.ru/document/1200084056 (Accessed 22nd February2020).

Calculation of traffic intensity. The calculation was carried out in two traffic directions, separately for transport and pedestrians. First direction: Selmash Avenue — 1st KonnoyArmii street. Second: Selmash Avenue (towards the suburban bus station). The section includes the number of vehicles and pedestrians per 1 hour. The calculation was performed during the peak hours of 21.09.2019 from 8.00 to 9.00, 22.09.2019 from 12.00 to 13.00 and 23.09.2019 from 17.00 to 18.00.

The measurement results are shown in tables 2-7.

Table 2

Types of vehicles participating in the traffic flow 21.09.2019 8.00–9.00

Types of vehicles	Traffic intensity, units/h								Total
Passenger car	374	72	61	289	190	111	214	482	1793
Truck	—	11	12	—	10	4	—	—	37
Bus	32		—	32	36			36	136
Minibus	18		—	18	16			16	68
Motorcycle	2	2	—	—	—			—	4
Tram	—	—	—	—	4	4	—	—	8
Total	426	85	73	339	256	119	214	534	2046

Table 3

Types of vehicles participating in the traffic flow 22.09.2019 12.00-13.00

Types of vehicles	Traffic intensity, units/h								Total
Passenger car	285	102	85	314	196	95	252	403	1732
Truck	—	17	11	—	17	12	—	—	57
Bus	28		—	28	32			32	120
Minibus	18		—	18	16			16	68
Motorcycle	2	2	—	—	—			—	4
Tram	—	—	—	—	4	4	—	—	8
Total	333	121	96	360	265	111	252	451	1989

Table 4

Types of vehicles participating in the traffic flow 23.09.2019 17.00-18.00

Types of vehicles	Traffic intensity, units/h								Total
Passenger car	411	80	72	304	200	135	201	342	1745
Truck	—	5	2	—	7	8	—	—	22
Bus	30		—	30	34			34	128
Minibus	21		—	21	18			18	78
Motorcycle	4	4	—	—	—			—	8
Tram	—	—	—	—	3	3	—	—	6
Total	466	89	74	355	262	146	201	394	1987

Table 5

The average daily intensity of traffic flow

Types of vehicles	Traffic intensity, units/h								Total
Passenger car	357	85	73	303	196	114	223	409	1760
Truck	—	11	9	—	10	8	—	—	38
Bus	30		—	30	34			34	128
Minibus	17		—	17	17			17	68
Motorcycle	3	3	—	—	—			—	6
Tram	—	—	—	—	4	4	—	—	8
Total	407	99	82	350	261	126	223	460	2008

The calculation of traffic intensity in the given cars/hour is calculated using the general formula [4]:

$$N = \sum_{i=1}^{n} N_i K_{\text{пр}i},$$

whereN_i — the traffic intensity of the given type of car, cars/h; $K_{\text{пр}i}$ — the reduction coefficient for this group of cars; *n* — the number of car types.

Table 6

Traffic intensity coefficient in the cars shown/hour [5]

Types of vehicles	Coefficient
Passenger cars	1
Motorcycles	0,5
Trucks	2
Buses	2,5
Minibuses	1,5
Tractors	3

Traffic intensity in the cars/hour for the intervals 8.00–9.00, 12.00–13.00, 17.00–18.00 is calculated using the above formula [6]:

$$N = 1793\times1+37\times2+140\times2,5+68\times1,5+4\times0,5 = 2321 \text{ (cars/hour)},$$

$$N = 1732\times1+57\times2+128\times2,5+68\times1,5+4\times0,5 = 2270 \text{ (cars/hour)},$$

$$N = 1745\times1+22\times2+134\times2,5+78\times1,5+8\times0,5 = 2245 \text{ (cars/hour)}.$$

The average daily traffic intensity in the cars/hour is calculated using the formula [7]:

$$N = 1760\times1+38\times2+136\times2,5+68\times1,5+6\times0,5 = 2281 \text{ (cars/hour)}.$$

The coefficients of distribution of traffic intensity depending on the time of observation are shown in table 7.

Table 7

The distribution coefficients of traffic density[2]

Hours	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8
Coefficient	0,083	0,025	0,009	0,023	0,059	0,144	0,270	0,32
Hours	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16
Coefficient	0,52	0,68	1,0	0,84	0,74	0,75	0,83	0,97
Hours	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–0
Coefficient	1,05	0,95	0,9	0,47	0,26	0,24	0,19	0,12

Figures 2-5 provide visualized data on traffic intensity [8].

2Gosavtoinspektsiya [Road Safety Unit]. Available from:https://xn--90adear.xn--p1ai/r/61 (Accessed 24th September2019).

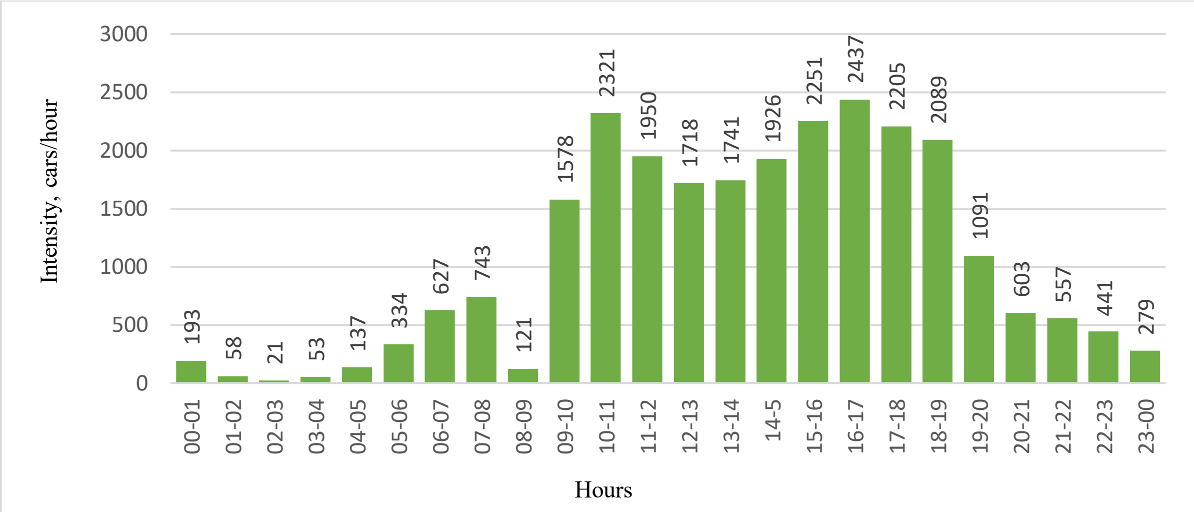

Fig. 2. Traffic intensity 21.09.19

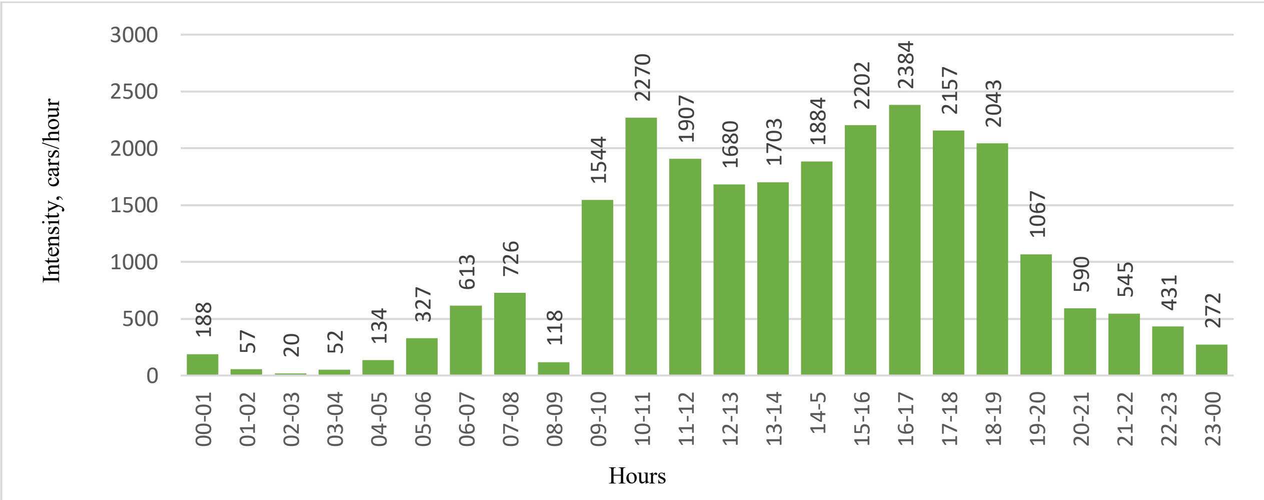

Fig. 3. Traffic intensity 22.09.19

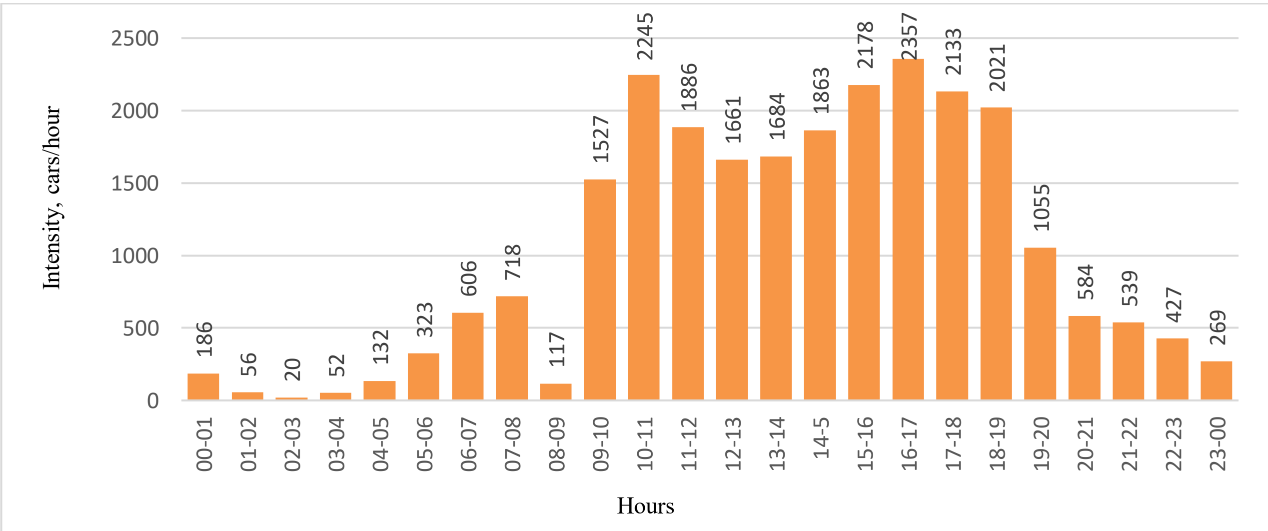

Fig. 4. Traffic intensity 23.09.19

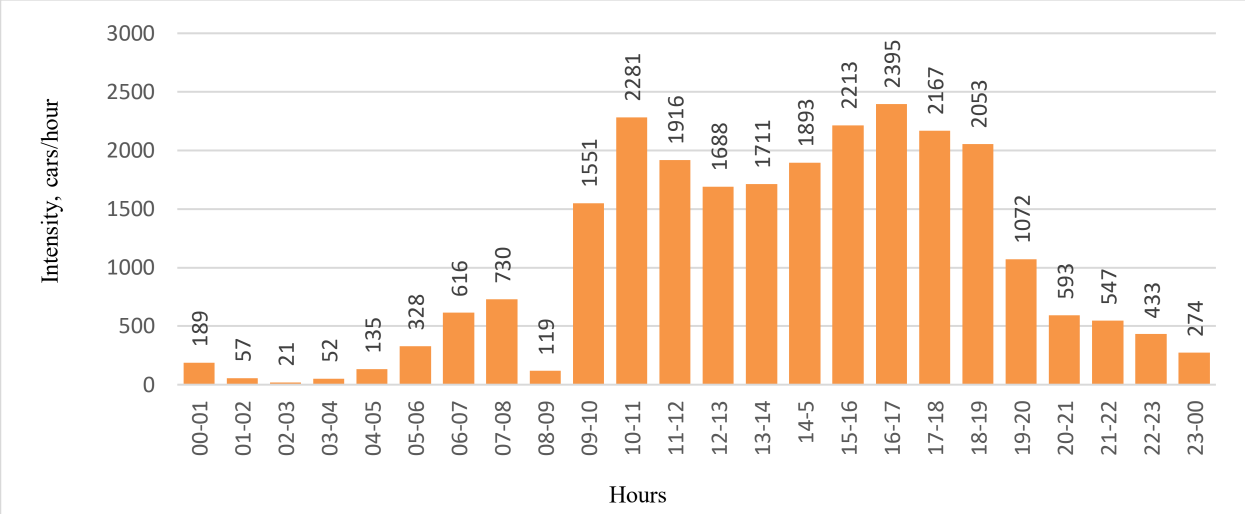

Fig. 5. Average daily traffic intensity dynamics

Observations have shown that the traffic flow in the study area consists of almost 90% of passenger cars (Fig. 6).

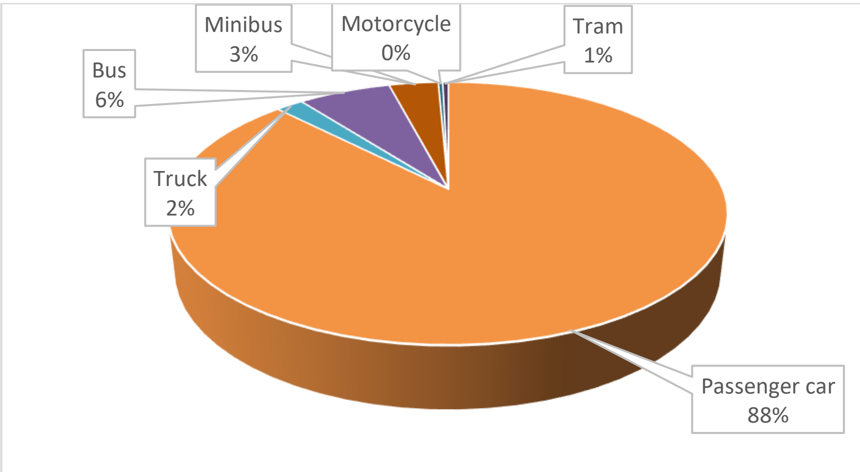

Fig. 6. Types of vehicles involved in road traffic

Table 8

Daily average intensity of movement of pedestrians

Direction	1	2	3	4	5	6	7	8
Intensity, units/hour	117	110	104	100	128	100	121	106

Data from Table 8 are visualized in Fig. 7.

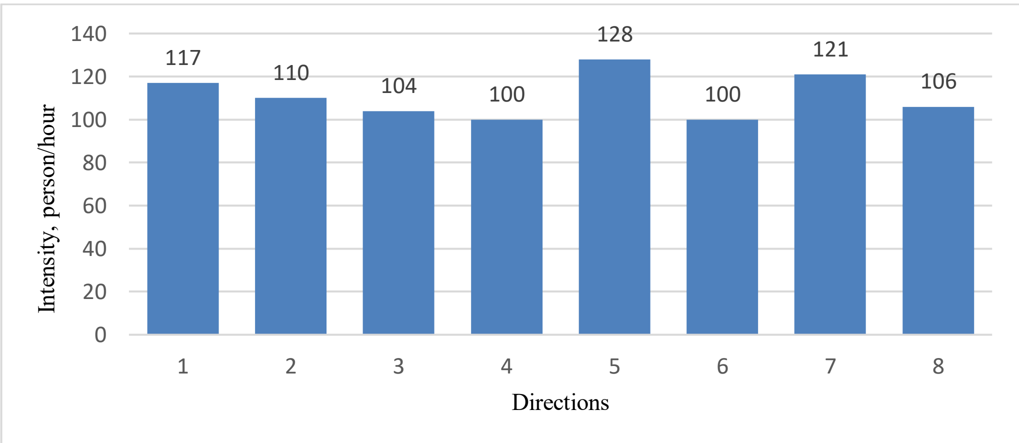

Fig. 7. The intensity of pedestrian traffic at the intersection

The results obtained are recorded on a conditional cartogram (Fig. 8).

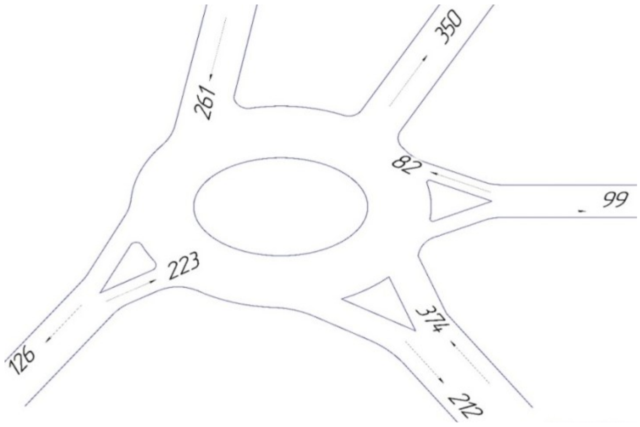

Fig. 8. Cartogram of traffic intensity at the intersection

Conclusion. The intensity and composition of traffic flow are taken into account when designing traffic control systems, developing the street network, and developing the general plan of the city. The data about the vehicles involved in the flow determines its speed. In order to approximate the calculated values of this speed to the real ones, the actual speeds of the prevailing modes of transport should be taken into account.

The results of the study of the intensity of transport and pedestrian traffic suggest that for the section under consideration, the peak hours are at 10.00 and 17.00. The intensity gradually increases up to 10 hours. From 11.00 to 19.00, the intensity changes slightly, and then decreases.

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Contribution of the authors

R.S. Durov — collection and analysis of literary data, participation in research, critical analysis, editing. E. V. Varnakova — literary and patent analysis, participation in theoretical research, text editing. K.O. Kobzev — scientific supervision, formulation of the main research concept and structure of the article. N. D. Kobzeva — methodology of the study, statement of the problem.

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Innovative fire-fighting technologies: patentological prospects

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Introduction. Currently, there are increasing threats of wildfires that destroy landscapes, economic objects and human lives.

Problem Statement. The purpose of this study was to compare some innovative technologies for extinguishing wildfires and study the prospects for research in this direction.

Theoretical Part. Technologies for extinguishing wildfires are being developed in several empirical directions. We use aerosols of metal-containing compounds and dispersed liquids with gas, as well as unmanned remotely controlled aircraft for extinguishing forest fires. For crown forest fires, a fire barrier is used. To extinguish peat fires in hard-to-reach places, a helicopter equipped with fire-fighting missiles is used. Peat fires are also extinguished by creating a vertical curtain using fast-hardening foam based on a solution of carbamide-formaldehyde resin. According to the concept of patentology, technology is considered as a set of functionally related technical objects and methods protected by patents, based on their innovative significance. System-forming elements in this case are concepts based on the characteristics of both technical objects and technologies, and patent objects.

Conclusion. It is advisable to build long-term plans for creating patent objects in the field of extinguishing natural fires. It is necessary to consider the scope of the patent results and outcomes of patentological analysis in accordance with the basic criteria of achieving a technical result of design technology, degree of innovation and empirical orientation.

Keywords:innovative technologies, patent, patentology, firefighting, natural fires, patentologicalresearch prospects.

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Introduction. Forests cover 1179 million hectares on the territory of the Russian Federation, or about a third of the world's forest area. Forest fires have a negative impact on the natural environment, including the condition of forest ecosystems. Forest areas are decreasing, and carbon monoxide and pyrolysis products are released into the atmosphere [1, 2]. At the same time, we are aware of increasing threats of wildfires that destroy forests, other natural landscapes, economic objects, and sometimes human lives. Peat fires are also very dangerous, which are often accompanied by the release of highly toxic smoke. Long-term smoke in cities and localities often leads to the development of diseases with severe dysfunction of pulmonary and cardiovascular systems. Issues of large cross-border fires are already being discussed at the international level [3]. Fires lead to the death of forests in large areas [4], and global climate change can worsen this situation, increase the area of their distribution and increase the degradation of forest conditions, i.e. it will become a global biosphere problem [5].

In recent years, the development of new technologies aimed at preventing and extinguishing forest fires has been updated in the world [6]. In favor of this argument, data from I.R. Shegelman and L.V. Shchegoleva [7] show that out of 14 Russian inventions for protection from forest fires, only six were devoted to methods for determining the location of fire localization and fire hazard control, while eight were devoted to extinguishing technologies. Some researchers have purposefully studied new technical solutions for detecting, preventing and extinguishing forest fires [8]. From the authors' point of view, the problem of extinguishing natural fires is relevant not only for forests, but also for peatlands. Thus, the analysis of some existing innovative technologies for extinguishing wildfires and the study of patentological aspects in this direction are quite relevant.

Basic means and methods of natural fires extinguishing. Currently, many innovative high-performance technologies and tools have been developed and are being used to extinguish wildfires. Modern classification of technical means of natural (forest) fires extinguishing [9] includes:

- tools for monitoring the occurrence and localization of forest fires;
- specialized equipment for transporting fire-fighting equipment and firefighters to the place of extinguishing;
- completely new driverless vehicles;
- means of protection of members of fire brigades.

A.G. Shmakov and co-authors [10] proposed to use a mobile generator of controlled dispersion for fire extinguishing, which can be used to suppress flaming or smoldering. The proposed fire extinguishing method using fine aerosols reduces tenfold the flow rate of the process fluid. Metal-containing compounds are promising for use as flame-arresters [11]. It is also believed that chemical compounds can be highly effective inhibitors such as K3[Fe(CN) [Fe (CN) [Fe (CN)6] (potassium ferricyanide) and K4[Fe(CN) [Fe(CN) 6] (potassium ferrocyanide). In this regard, the use of finely dispersed aerosols of potassium compounds and dispersed liquid with gas [12] leads to effective extinguishing of flame foci.

Modern innovative technologies for forest fires extinguishing. The study of the current state and use of innovative technologies for forest fires extinguishing was conducted by N.A. Korshunov and co-authors [13]. The experts selected promising criteria for these solutions: novelty, effectiveness, and positive experience. In particular, it is assumed that a promising technological solution must be confirmed by its practical use in fires extinction, i.e. the declared or actual effectiveness of the technological solution must be proven in practice. The maximum possible readiness of the proposed solution for its potential mass implementation is highly appreciated. At the current stage the novelty of research is shown in the choice of directions for the development and implementation of the most effective promising solutions in the practice of fire extinguishing, which determine the patterns of practical use of optimal methods and technologies not only for extinguishing, but also for fire detection. For example, an important area was the study of the use of unmanned remotely controlled helicopter-type aircrafts equipped with video cameras for fire reconnaissance. These devices can help reduce the risk of injury and death of firefighters, and timely detection of areas with the resumption of peat smoldering can significantly reduce the economic and environmental damage from such fires. The original direction in firefighting is individual small-scale mechanization of a forest firefighter due to the motorization of hand tools (the use of a knapsack forest fire extinguisher and personal exoskeletons). There are interesting and promising proposals for the creation of aviation fire barriers in the form of protective strips using fast-hardening foam compositions. Currently, this technology is at the stage of experimental research.

M.A. Sheshukov and co-authors suggested that to protect localities from forest fires, they should be bordered by firebelts with firelines of poplar seedlings planted in a line (up to 40 rows in a line) [14]. B.N. Borisov and his co-authors developed a barrier for fighting top-level forest fires. It includes a protective cloth made of fireproof material, fixed on vertical rods [15].

As a result of a brief patent and information search for technical solutions in the field of forest fire extinguishing, N.S. Kovalek and M.V. Ivashnev [16] considered the prospect of using the method of soil throwing. Researchers offer technical solutions:

- prevention of the release of the top of the forest cover in the area of the edge of the fire;
- moving the soil with thrower-cutters and guide-plates at an angle to the edge of the fire;
- concentration of soil directly in the zone of a moving fire.

In their research, the authors used an original methodology for the synthesis of patentable intellectual property objects, based on functional and technological analysis of engineering creativity, generalization of analysis and

synthesis of technical systems, taking into account the natural specificity of the functioning of modified technologies [17].

New technologies for using aviation to extinguish forest fires. The use of the VSU–5A helicopter spillway device with the supply of wetting agents and foaming agents is highly effective. However, the air-mechanical foam used in this case when laying protective fire lanes, protects only briefly in the process of fire extinguishing [18]. Currently, a new technology for forming chemical foam using a pump and compressor system has been developed. The technology is based on injecting a dosed amount of foaming agent and a fire-resistant chemical agent, followed by injecting air into this mixture in certain proportions. The formation of a composition for extinguishing fires, creation of a support and control lines occurs in the mixing chamber. Depending on the content of compressed air in the foam, "wet" or "dry" foam is obtained. The latter is more adhesive and can be held on vertical planes for a relatively long time. "Wet" foam has greater mobility, and therefore is suitable for the suppression of burning edges. NPO SOPOT and ITMO University (Saint Petersburg) modified the foam mixing technology to create fire-resistant fast-hardening foam from structured silica gel nanoparticles that repeat the morphology of air bubbles dispersed in solution [19].

New firefighting technologies are also being developed to localize and extinguish fires in remote areas, in case of high-altitude forest and steppe fires. To implement this technology, a helicopter with fire-fighting missiles equipped with a dispersing charge, a sensor for the selected parameter, and a fire extinguishing agent is required. Such a missile is triggered on the ground. In this case, the package with the foaming agent breaks, which, mixing with water, fills the barrel. The reagents form fire-extinguishing foam covering the combustion center [20]. In 2016, S.I. Zhiltsov and P.N. Petukhov proposed a technologically new device based on amphibious hydro-aeroplanes to extinguish forest fires from the air with a fire-extinguishing liquid [21].

New technologies for peat fires extinguishing. The analysis of existing technical solutions designed to extinguish forest fires has shown that their use in the elimination of peat fires is not practical, since the epicenter of peat burning may be located at a depth of a fire. I.D. Badin and co-authors suggested using "A device for extinguishing fires on peatlands" using helicopters [22]. The principle of operation of the device is the depressurisation of the cylinder with carbon dioxide when it hits the ground, decomposition of carbon dioxide into water and carbon dioxide, which under pressure spreads under the surface of the peat to the depth and blocks the access of oxygen to the fire. The device allows you to quickly and effectively eliminate peat fires, including hard-to-reach places.

Another technological approach to fighting peat fires is to create a vertical curtain. In particular, N.P. Kopylov and V.I. Zabegaev developed a method for local firefighting, according to which fast-hardening foam based on water, solution of amino-formaldehyde resin, foaming agent, concentrated sulfuric acid, and target additives containing liquid glass and formamide are used when creating a vertical curtain [23].

The principle of extinguishing a fire by isolating the hearth from oxygen is also discussed in another technological version proposed by the same authors. This is a technology for extinguishing local underground peat fires by flooding with water and capillary imbibition of all reservoir deposits. Next, they determine the boundaries of active local underground peat combustion centers and consistently move a helicopter with a multi-section tank to them. The tank is regularly filled with water in the necessary sections in accordance with the irrigation and fire-fighting map [24].

The original technological approach allows you to use the energy of explosives when extinguishing a fire. This method in arsenals for storing explosive materials increases the effectiveness of extinguishing and reduces the likelihood of uncontrolled explosion of ammunition. The areas where explosives are stored are covered with soil, in which the explosive charges are placed. Their explosions move the soil of the embankment, filling in the fire place. The method can be used for extinguishing forest and underground fires over large areas [25]. For extinguishing peat fires on large areas V.I. Zabegaev and N.P. Kopylov proposed a method, the essence of which consists in laying moles on the lower level of peat formation. They detonate the cord explosive placed in them with the formation of a ditch, at the bottom of which they form a fire-prevention gap from the mineral layer of the earth [26].

Patentological prospects of research in the field of fighting wildfires. Patentological essence of the concept is inextricably linked with the structural-integrative approach. The concept of patentology and its general characteristics were developed by V.M. Evstropov in 2017 [27]. According to this concept, technology is considered as a set of functionally related technical objects and methods that are protected by patents, based on their innovative significance. The system-forming elements are concepts based on the characteristics of both technical objects and technologies (technical characteristics) and patent objects (utility models, devices and methods). Stages of patentological research may include [28]:

- pre-processing of patent arrays for a given topic;
- formation of a thematically restricted locus of patent data;
- patentological analysis of the obtained results;
- analysis of technologies in terms of classification.

The patent locus is positioned as the desired part of the patent cluster — a thematic set of patents linked by functional vertical and horizontal links. Vertical links are provided by the chronological development of the patent and technical object. Horizontal links are understood as links between groups of inventions and utility models that form the patent locus, including the patent objects themselves, as well as their analogues. New patent research based on the patentological approach can optimize the creation of modern patent and technical solutions used for extinguishing forest fires [29].

The patentological approach can optimize the activities of modern innovative engineering [30], for example, when developing methods for using robotics in extinguishing natural fires. At least, currently, the work is under way to create robots (drones) for multi-functional and tactical purposes, including the creation of unmanned aerial vehicles [31]. In addition to the robotization of forest fire extinguishing, the prospects of creating an intelligent system for controlling extinguishing processes by equipping members of forest fire brigades with intelligent devices are discussed [32].

Conclusion.A comparative analysis of some modern technologies and patent directions of forest fire extinguishing is carried out. Based on the analyzed data, we comes to the conclusion about the feasibility of building long-term plans for creating patent objects in the field of extinguishing natural fires, taking into account the loci of patent results and their patentological analysis. These measures should be carried out in accordance with the main criteria for achieving the technical result of the designed technologies, the degree of innovation and empirical orientation (creation of fundamentally new technical means for extinguishing natural fires, etc.).

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Method of machine reliability optimization using integral indicator

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Introduction. For a long time, the issues of improving the reliability of machines using the integral indicator have remained relevant. The operation of hydromechanical excavator elements is considered from the standpoint of structural safety.
Problem Statement. The paper shows the method and algorithm used to calculate the stretching of the excavator implement.
Theoretical Part. The study has identified the ways to improve reliability using the integral reliability indicator. The authors have obtained the equations: for the steel fatigue strength; for the stress concentration factor; for the effective stress in the dangerous section and the stretch life. The distribution of methods for managing the integral reliability indicator by the stages of the machine's life cycle is presented. It is noted that in order to obtain an optimal strategy for improving the excavator reliability, it is necessary to minimize the value of the integrated reliability indicator. The method of complex analysis of input factors is developed, and for serial and mass production — a general set of recommendations for increasing the component life. The distribution of disadvantages by structural, technological and operational factors for shafts, axles, gears, metal structures, chains, and special parts is obtained. The methodology for creating virtually trouble-free machines, including principles, a comprehensive program and a reliability management system, is described.
Conclusion. The use of the proposed system makes it possible to develop and manufacture high-reliability machines and to ensure a systematic reduction in the integral reliability indicator. The functioning of the machine reliability management system guarantees their creation with the same level of reliability, which will ensure the competitiveness of the equipment and the absence of consumer complaints.

Key words: reliability of machines, integral reliability indicator, gamma-percentile life.

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Introduction. Early failures during operation of the machine significantly reduce its life. Moreover, failures can provoke situations that affect the safety of special equipment operation. Thus, an urgent issue is to improve the reliability of the machine using an integral indicator. Operation of elements of the EO-4117 hydro-mechanical excavator is considered from the point of view of structural safety.

Problem statement. This paper shows the method and algorithm used to calculate the stretching of the EO-4117 excavator implement [1-3].

Theoretical part

Determination of ways to improve reliability with an integral reliability indicator. Empirical integral distribution curves of the parameters are approximated by the curve parameter of the Weibull law, and the *i-th* parameter value is calculated according to the formula

$$X = C + A\sqrt[B]{-ln P(x)} \tag{1}$$

using probability values $P(x) = 1 - F(x)$ of a random value, which is calculated using a table of uniformly distributed random numbers between 0 and 1 (random number generator).

The resulting equations are presented below.

— For the endurance limit of steel 15HSND:

$$F(\sigma_{-1}) = 1 - exp\left[-\left(\frac{\sigma_{-1} - 168,8}{6,04}\right)^{2,57}\right]. \tag{2}$$

— For the stress concentration coefficient (from the roughness of the stretch surface):

$$F\left(k_{F\sigma}\right)=1-exp\left[-\left(\frac{K_{F\sigma}-0,85}{0,07}\right)^{2,65}\right]. \quad (3)$$

— For operating voltage in a dangerous stretch section:

$$F\left(\sigma_{cв}\right)=1-exp\left[-\left(\frac{65,0-\sigma_{cв}}{12,1}\right)^{2,32}\right]. \quad (4)$$

— For a stretch resource:

$$F\left(T_{p}\right)=1-exp\left[-\left(\frac{T_{p}-10,1}{28,1}\right)^{1,49}\right]. \quad (5)$$

Having considered the structure of the integral reliability indicator and analyzed the results of calculations of individual reliability indicators, we have established controlled indicators (parameters). Control actions for changing the values of managed indicators are ways (measures) to improve reliability (table 1)

Table 1

Distribution of methods for controlling the integral reliability indicator by stages of the machine life cycle

<table>
<tr><th colspan="2">Methods for controlling the integral reliability indicator</th></tr>
<tr><td>Developmentstage</td><td>1. Increasing the resource of parts of the limiting group.
2. Optimization of the range and quantity of spare parts.
3. Optimization of differences on the parameters of parts that cause resource dispersion.
4. Increasing the frequency and reducing the volume of maintenance operations.
5. Optimization of the range and quantity of spare parts, tools and accessories.
6. Adjusting the machine design to reduce the complexity of replacing parts and assembly units.
7. Optimization of the resource, weight and cost of parts with fatigue failures.
8. Reducing the metal content of parts and assembly units that do not fail for the resource (service life).
9. Optimization of the machine diagnostics system.
10. Optimization of the volume and frequency of preventive replacement of parts (assembly units).
11. Optimization of the volume and frequency of the current repair of the machine.</td></tr>
<tr><td>Productionstage</td><td>12. Introductionandoptimizationof:
— input control of main materials and components;
— operational control of manufactured parts;
— output (acceptance) control.</td></tr>
<tr><td>Operationstage</td><td>13. Selective implementation of methods from 1 to 11 based on the analysis of operational information about the reliability of serial (mass) machines in various operating conditions.</td></tr>
</table>

The structures of the integral reliability indicator and ways to increase the reliability of the excavator and reduce its integral indicator are synthesized (Fig. 1).

Development stage

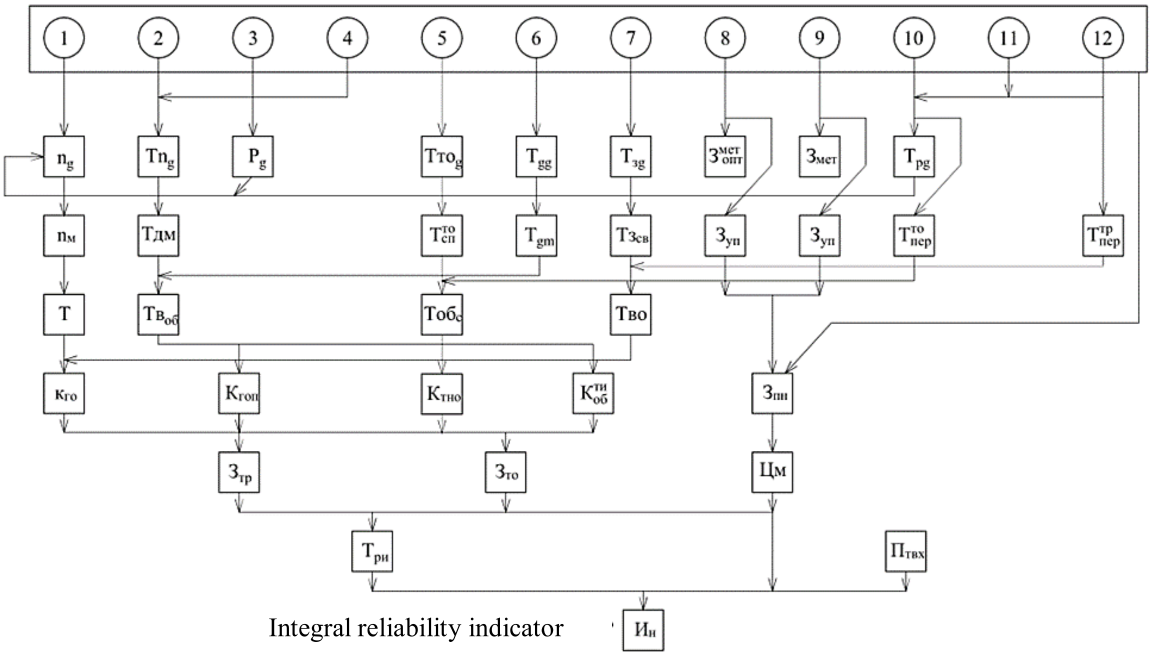

Fig. 1. Relationship of methods for increasing reliability with the integral reliability indicator

Determination of integral indicator control methods. To obtain an optimal strategy for improving the reliability of the excavator, it is necessary to minimize the value of the integral reliability indicator:

$$И_H = f\left(C_{cj}\right) \to min\,,\ j = 1,2,...,n\,. \tag{6}$$

Here C_{cj} — the total cost per unit. These include operating costs, damage from insufficient reliability, and the cost of developing and implementing the *j-th* strategy to improve the reliability of the machine:

$$C_{cj} = \sum_{i=1}^{n} C_{ci}\,,\ i = 1,2,...,m\,, \tag{7}$$

where C_{ci} — specific total costs (including operating costs from insufficient reliability, the cost of developing and implementing the *i-th* method of increasing the reliability of the machine).

Building an optimal strategy for controlling the process of increasing the machines reliability is in optimizing each control step— the implementation of the M_i method (event) in accordance with the degenerate problem of dynamic programming [4–6].

As an optimal criterion ω_i for the control step U the efficiency of increasing the reliability K_j of the machine is accepted:

$$\omega_i = Э_i / З_i\,,$$

where— the economic effect of using the M_i method; $З_i$ — costs for the development and implementation of the M_i-method.

Efficiency at the *i-th* control step

$$\omega_i = \omega_i\left(k_j, U\right), \tag{8}$$

and the optimal control strategy is as follows

$$k_{jc} \to u_1\left(k_{jc}\right) \to k_{j1} \to u_2\left(k_{j1}\right) \to ... \to k_{jm-1} \to u_m\left(k_{jm-1}\right) \to k_{jm}\,. \tag{9}$$

The optimal control strategy depends on time constraints or funds (in most cases simultaneously for these two indicators) for the development and implementation of activities. An additional condition of the task is a forced sequence in the implementation of certain measures.

Additive performance indicator for all steps of the process:

$$W_i(k) = \max_{U_i}\left\{w_i\left(k_j, U\right) + W_{i+1}\left(F_i\left(k_j, U_i\right)\right)\right\} \quad (10)$$

provided that maximum efficiency must be obtained in the shortest possible time, i.e.

$$w_i = \left(k_{ji}, U_i\right) \geq w_{i+1}\left(k_{j+1}\right). \quad (11)$$

The value of the reliability indicator for the *i-th* control step:

$$k_{ji} = F\left(k_{ji-1}, U_i\right). \quad (12)$$

Three variants of the strategy were developed to improve the reliability of excavators, and the total effectiveness of measures was calculated.

Improving the structural reliability of machines. Considering ways to improve the structural reliability of machines, it is advisable to show the principles of establishing and classifying the causes of failures of parts caused by a deviation of any parameter (factor) of strength and load from the nominal value (or going beyond the tolerance range). A comprehensive (system) analysis of parameters and their structure allows you to set drop-down parameters and determine the proportion of their impact on the component life. To determine the causes of fatigue failures we applied functional method by which the relationship was found between input and output parameters (resources) of the part (Fig. 2).

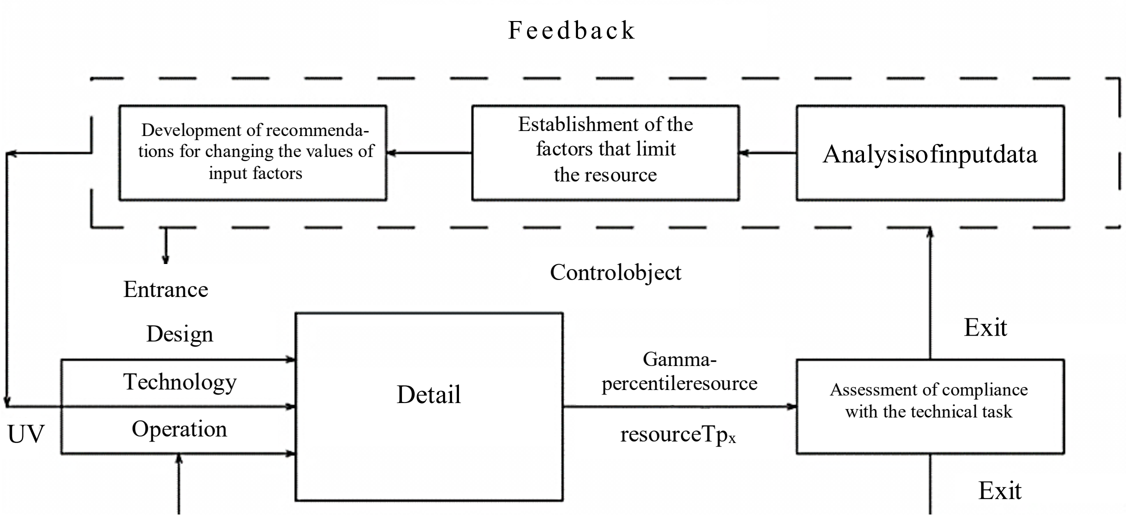

Fig. 2. Block diagram of the functional method to determine the causes of failures and increase gamma-percentile component life

The authors have developed a method of the complex analysis of the input factors (Fig. 3), and for batch and mass production — a general set of recommendations to increase components life [7, 8].

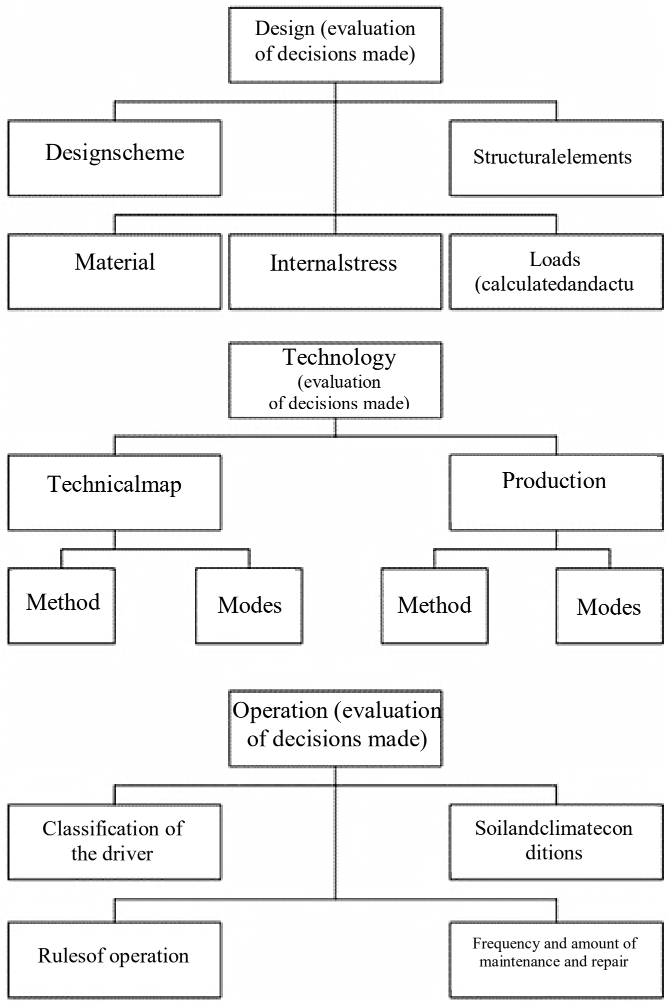

Fig. 3. Structure of complex analysis of input factors of a detail

The conditions are obtained (depending on the necessary information) under which one of the three developed functional models should be applied. A functional model with strain-gage testing and refined parameters was applied to determine the causes of failure and increase the life of the axis in the support of the E-652B excavator boom. Another functional model (with updated parameters) is used for gears, shafts, metal structures of excavators E-652B, EO-4111V, EO-3322A, EO-3322B.

As a result of research to eliminate the causes of failures of various parts of excavators E-652B, EO-4111B, EO-3322A, EO-3322B using the functional method, the following distribution of disadvantages by design, technological and operational factors was obtained:

— shafts and axles — 29 %, 59 % and 12 %;
— gears — 36 %, 55 % and 9 %;
— metal structures (frames, arrows, handle, bucket) — 31 %, 51 % and 18 %;
— chains with steps of 14.5 and 87.1 mm — 34 %, 62 % and 5 %;
— special parts — 42 %, 51 % and 7 %;
— average values are 34 %, 55 % , and 11 %.

The design includes 37% of the recommendations, 28 % — technology 5 % — equipment, 11 % — snap-in, control operations — 19 %.

It is established that in some cases, the reasons for short component life are significant deviations in the parameters of loading and load-bearing capacity. Thus, the radii of the shaft and spline shafts are understated by 2-3 or more times. The roughness of the surface of the sprockets of gears and shafts is significantly lower than the requirements of the drawing. The legs of the weld metal are understated by 2-3 times. The hardness of the surface and core of shafts, gears, chains is 1,2–2 times lower than the requirements of the drawing (Fig. 4) [9-12].

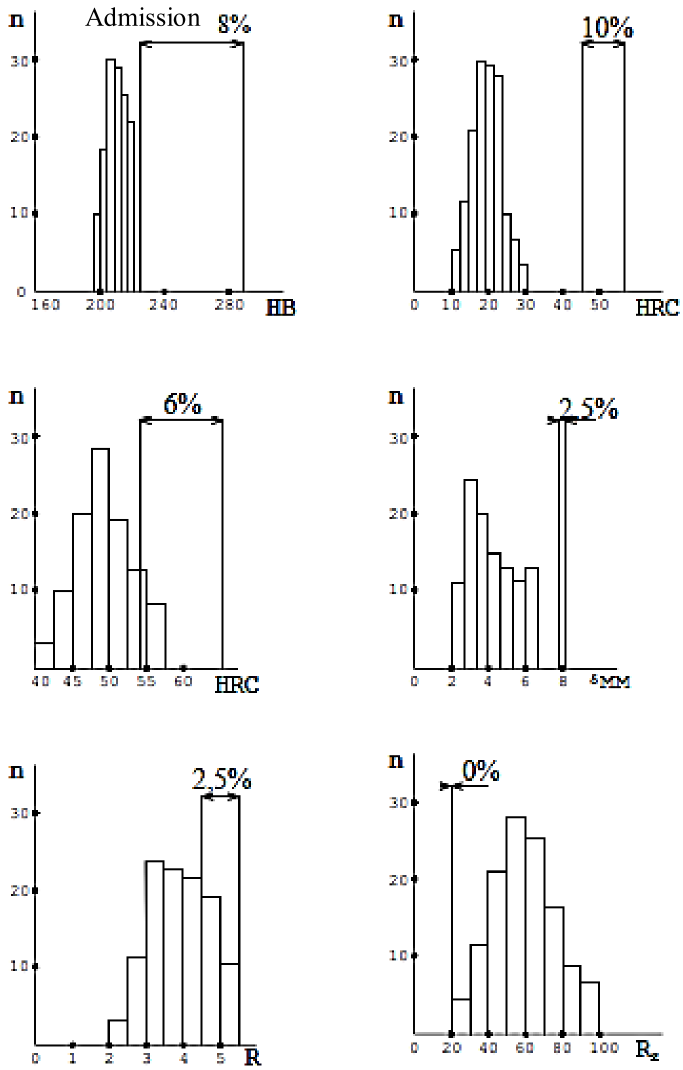

Fig. 4. Dispersion of part parameters and tolerance values in drawings: HB — Brinell hardness,
HRC — Rockwell hardness, n — sample values

From a sample analysis of detailed drawings of several models of excavators with mechanical and hydraulic drive, it is clear that the tolerances for these parameters are almost not set. Working drawings for various parts have up to 50-80 or more sizes, as well as strength data. However, only 2-5 dimensions, including strength data, affect the dispersion of the components life.

Theoretical basis is developed for a multilevel connection of tolerances on the parameters of loading and the bearing capacity with the components life. A multi-variant dependence of the coefficient of change in the components life on the coefficients of change in load and load-bearing capacity is obtained (power dependence with a power indicator from 1 to 20). The structure of endurance and load factors is compiled. The types of detail parameters (geometric, strength and dynamic), as well as the types of its factors (simple and complex) are classified. The structure of the main composition of factors and parameters of typical parts in the system "factor — parameter — value — tolerance for the coefficient of increase or decrease in load capacity or load — this coefficient with a tolerance — tolerance for the parameter" is obtained. The types of statistical distributions of part parameter values depending on the features of technological processes are considered. The densities of the components life distribution are compared in two cases: with and without tolerances for the part parameters [13-15].

The methodology for creating virtually trouble-free machines, including principles, a comprehensive program and a reliability management system, is described. Based on the generalization of the accumulated experience in ensuring reliability, 16 principles for creating virtually trouble-free machines have been formulated for the first time (table 2).

Table 2

Principles for creating virtually trouble-free machines

1.	Changing the reliability of the machine entails a change in the cost of its development, production, and operation	9.	For the main parameters of parts, tolerances are assigned to ensure an acceptable dispersion of their resource
2.	To measure changes in the reliability of a machine, a single indicator is used that generalizes all the reliability properties (i.e., the integral reliability indicator)	10.	Considering random variables (strength, load, operating time) that are bounded from above or (and) from below, theoretical laws are applied with similar restrictions (limits)
3.	To evaluate the changes and optimize the reliability of the machine (element), the specific total costs for the development, production, and operation is used as an integral indicator	11.	To calculate the distribution function and the minimum resource, dependencies are used that relate the resource to the load capacity and bearing capacity, and the Monte Carlo method
4.	Virtually trouble-free resource of the machine should be optimal	12.	The calculated reliability of the machine is confirmed experimentally before the start of mass production: for the full life of the machine and with the acceptable reliability
5.	The minimum resource of each part must be greater than the specified (optimal) resource of the machine $min\, T_{Pgi} > T_{PHopt}$	13.	Control in production provides a predetermined distribution of the bearing capacity of the part
6.	Planned replacements of some parts are allowed	14.	The design, technical parameters and operating conditions of the machine ensure the specified load dispersion
7.	For details, there may be rare accidental failures, the causes of which cannot be determined, since there are no necessary methods and technical means	15.	Maintenance (lubrication, adjustment, diagnostics, etc.) of the machine maintains the specified level of reliability
8.	To produce spare parts for planned replacements, to eliminate accidental failures to have a stock of parts	16.	If the test conditions of experimental machines (units, assemblies) do not meet all operating conditions, you must additionally obtain information about the reliability of serial machines

These principles formed the theoretical basis for the methodology of system-based step-by-step reliability assurance at all three stages of the machine's life cycle. The basic principle of creating virtually trouble-free machines: the minimum resource of each part (shift parameter, three-parameter Weibull distribution) must be greater than the specified resource of the machine.

Technical and economic calculations for the design of the hydro-mechanical excavator EO-4117 showed that repair costs are reduced by 10-20 times, and the integral reliability indicator — by 3-6 times. To increase the life of the machine from 10 to 20 thousand hours, you will need to increase, for example, the section of metal structures by 19 %, transmission parts — by 9 %. The cost of steel for one excavator increases by 0,45 thousand rubles. (from 3 to 3,45), and the price — from 20 to 20,45 thousand rubles, i.e. by 2,3 %. The integral reliability indicator is reduced by 1,97 times, and the weight of the excavator increases by about 15 %.

Conclusion. The application of the proposed system makes it possible to develop and produce high-reliability machines and ensure a systematic reduction in the integral reliability indicator. The functioning of the machine reliability control system guarantees their creation with a level of reliability that will ensure the competitiveness of equipment and the absence of consumer complaints.

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Contribution of the authors

V.E. Kasyanov — scientific supervision, formulation of the main idea of research, verification of formulations and terminology. D.V. Demchenko — analysis of literary sources, control of the adequacy of the research. E. E. Kosenko —research, participation in theoretical research, setting up and description of scientific experiment. S. V. Teplyakova —research, participation in the formulation of scientific experiment, description of scientific experiment.

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Assessment of load of load-bearing elements of the passenger elevator based on regular monitoring results

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Introduction: This article is devoted to improving the safety of elevators — the most popular hoisting-and-transport devices. The paper presents the results of an indirect assessment of load of load-bearing elements of elevators for residential buildings based on the results of regular monitoring by service organizations.
Problem Statement. Processing of the monitoring results was carried out on the basis of the idea of random nature of influencing factors and performance indicators. The data of observations of 15 elevator units of various load capacities installed in residential buildings with different number of storeys and passengers were processed.
Theoretical Part. The following indicators are accepted as the main ones, which characterize the load of the main elevator drive: machine time coefficient and specific number of starts per minute of pure machine time. For each of the indicators, distribution functions and probability densities are constructed.
Conclusion. Indicators of loading of the elevators vary within wide limits; no stable correlation between the indicators was established; each elevator is characterized by a pair of values of the machine time coefficient and the number of inclusions. The main purpose of the results is the possibility of using them to assess the adequacy of the formation of loading modes in the simulation of passenger elevators in comparison with real indicators.

Keywords:safety of elevators, monitoring the operation of elevators, actuator loading factors, ratio of computer time, switching frequency of the main drive, statistical characteristics of the operation modes of the elevator.

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Introduction. The elevator is one of the most popular and widely used lifting and transport devices [1]. The current technical regulations of the Customs Union define it as: "an elevator is a device designed to move people and (or) cargo from one level to another in a cab moving along rigid rails that have an angle of inclination to the vertical of no more than 15° [2].In this article, the term "elevator" is used in accordance with this definition.

In the Russian Federation, according to the National Elevator Union (NLS) and the National Association of Liability Insurers (NSSO), about 550 thousand elevators are operated, which are subject to the Federal service of Rostechnadzor in terms of ensuring safe operation. The number of elevators is increasing rapidly in line with the growth of multi-storey housing construction in the country.

Elevators are classified as high-risk equipment. According to the combined data of the NLS and NSSO, over the past three years, about 100 accidents occurred during the operation of elevators, in which 40 people were killed and about 100 people were injured.

Ensuring safe operation of elevators is a complex multi-faceted task, the complex solution of which is formulated in the current regulatory documents. Among the most important topical directions of solving this problem, the authors highlight the need for a well-founded methodological approach to planning and implementing maintenance programs for each elevator unit, taking into account the actual accumulated number of cycles and the equivalent level of loading [3-4]. This approach will ensure:

— guaranteed level of safety during the entire period of operation;

— possible stabilization of maintenance costs.

For reasonable planning of maintenance programs and repair impacts during the operation of elevator units, actual information about the operating modes of power elements, especially the main drive, is required — the duration of the switched-on state in each cycle of operation, the specific number of starts, brakes, etc. As it is known, elevators operate under the conditions of regular influence of random factors — the frequency of requests for their use, the value of the end load, the duration of the switched-on state, the frequency of starts, and many others [5-6]. Systematization and generalization of these impacts will create scientifically based requirements for the development of maintenance algorithms.

To create such a database, it is advisable at the first stage to use the materials of regular observations of the actual operating modes of elevators with objective recording of the results carried out by specialized service organizations. In the future, it is possible to create the necessary scientific and methodological base by developing procedures that are adequate to real processes for simulating the operating modes of elevator units and establishing the relationship between operating modes and operating loads [7]. This article uses the materials of regular monitoring and computer database of LLC Liftservis, Rostov-on-Don.

Taking into account the above mentioned information, the purpose of this work is to obtain regular observations of the laws of formation of loading modes for power elements of passenger elevators on the basis of statistical processing of data.

1. Methods of research and statistical processing of data from regular observations. The main stages of the study were as follows:

— selection of observation objects taking into account the influence of parameters and operating conditions of elevator units;

— substantiation of the main characteristics of the operation and loading modes of the elevator units (statistical distributions and average values);

— development of methods for processing raw data.

Residential buildings equipped with elevator units were selected as objects of observation. The main influencing factors are the floor of the house, the number of entrances and elevator units, and the availability of goods elevators. As a result of the analysis, six houses (6, 16, 21, and 24 floors) with one, two, and three entrances were selected with different levels of population density (Fig. 1). Quantitative parameters are given in table 1.

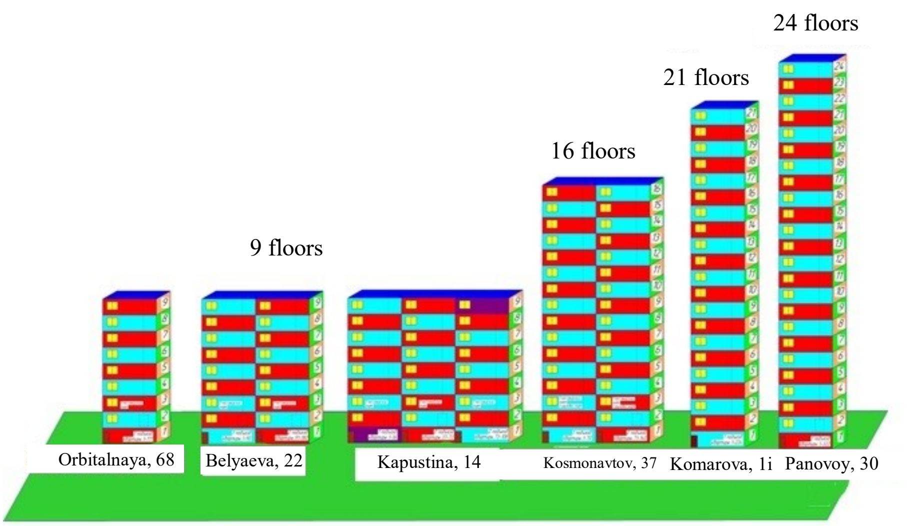


Fig. 1. Objects accepted for monitoring

Table 1

Quantitative characteristics of observational objects

Adress of the building	Number of floors	Number of entrances	Entrance	Type of the elevator (number on the pictures)	Loadcapacity, kg	Estimated number of residents served by the elevator
Orbitalnaya, 68	9	1	No. 1	Passenger (1)	400	513
Belyaeva, 22	9	2	No. 1	Passenger (2)	400	270
			No. 2	Passenger (3)	400	270
Kapustina, 14	9	4	No. 1	Passenger (4)	400	108
			No.3	Passenger (5)	400	108
			No.4	Passenger (6)	400	108
Kosmonavtov, 37	16	2	No.1	PassengerNo. 1 (7)	400	105
				GoodsNo. 1 (8)	630	105
Komarova, 1i	21	1	No. 1	PassengerNo. 1 (9)	400	168
				PassengerNo. 2 (10)	400	168
				GoodsNo. 1 (11)	630	168
				GoodsNo. 2 (12)	630	168
Panovoy, 30	24	1	No.1	PassengerNo. 1 (13)	630	322
				PassengerNo. 2 (14)	630	322
				Passenger № 3 (15)	630	322

The following monitoring results were taken as the initial characteristics of the operating and loading modes of the elevator unit, primarily the main drive (MD): the net time of on-state (t_{M}, s) and the number of starts (N_o) during each calendar hour. For each observed elevator, the initial indicators are obtained in the form of diagrams (fig. 2,3,4 and 5) or tables. The observation period was 10800 minutes (7,5 days, 180 hours).

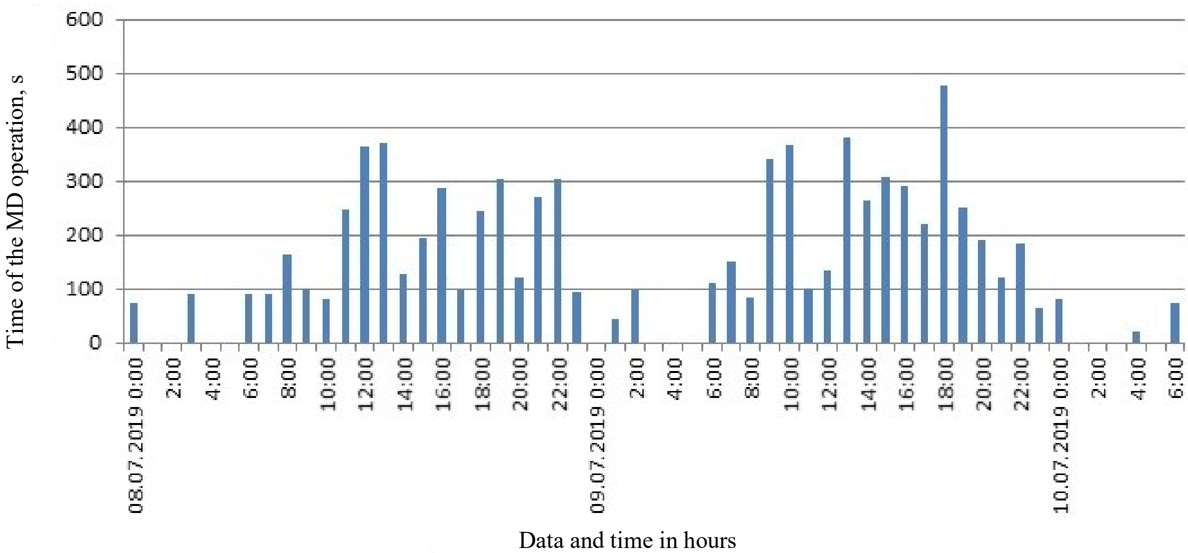


Fig. 2. Net operating time of the MD per hour (14 Kapustinastreet, entrance 3)

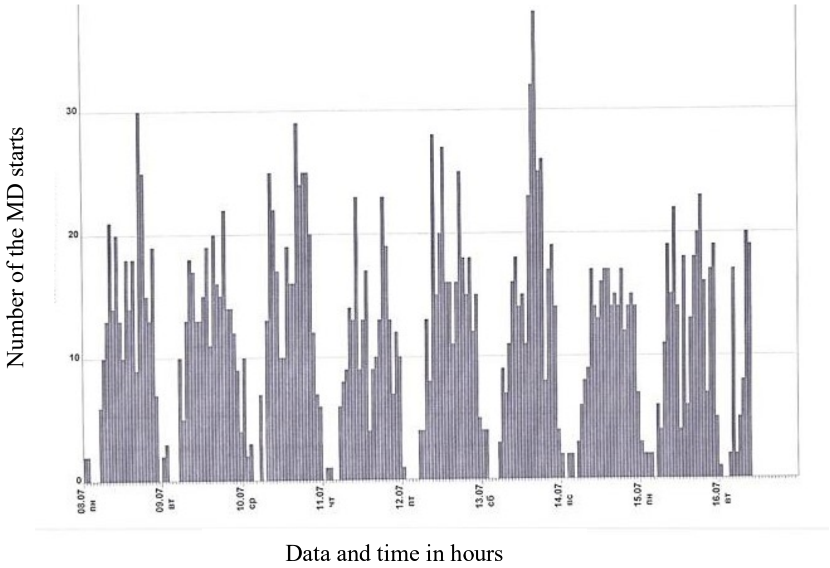


Fig.3. Number of GP starts per hour (14 Kapustinastreet, entrance 3)

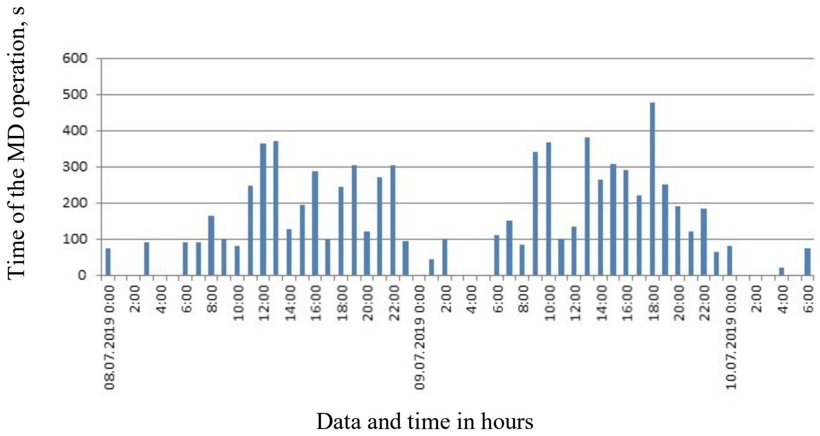


Fig. 4. Net operating time of the MD per hour (68 Orbitalnayastreet, entrance 1)

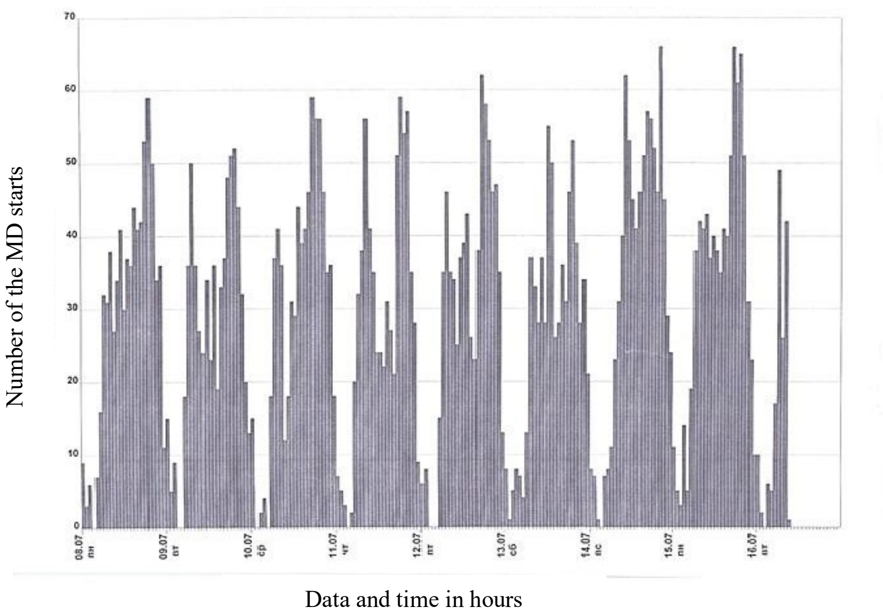


Fig. 5. Number of GP starts per hour (68 Orbitalnayastreet, entrance 1)

Figures 3 and 5 show samples of the source data used for subsequent statistical processing.
Program statistical processing was to obtain such characteristics: the duration of the elevator operation and

switching of the main drive, which, on the one hand, would serve as a basis for comparison of the loading actuator and other components of various elevator units, for the formation of generalized characteristics necessary to evaluate the adequacy of the experimental data and the results of plan simulation [8].

Based on these tasks, the indicators of the load mode of the elevator MD are:

— machine time coefficient K_m, as the ratio of the net to the total operating time of the elevator (and the MD) for the entire observation period;

— the specific number of the MD starts in the net machine time (starts per minute).

Each of these indicators characterizes different aspects of the operation mode of the elevator unit. The machine time coefficient K_m evaluates the relative duration of the engine's switched-on state, its thermal mode in comparison with the permissible one for this engine. The number of starts *n* determines the conditional level of dynamic loads during starts and decelerations.

Each of the selected indicators is a random variable, for the evaluation of which it is necessary to consider a set of numerical and functional characteristics [9]. Average values and average square deviations are used as numerical characteristics. Functional characteristics are represented by distribution functions F(x) and probability density f(x), where any of the considered indicators is taken.

The data processing procedure is as follows:

1. Processing is carried out for each elevator separately.
2. Creation of a complete unified set of data for each elevator for the entire period of multi-day observations, for each day — for 24 hours.
3. Every day table 2 is filled in: the coefficient of machine time k_m and the specific number of starts of the main drive of the elevator per minute of net machine time n.
4. The entire range of $k_м$ and n from the minimum to the maximum is divided into 10 equal parts; the ranges (digits) are numbered from 1 to 10. The ranges are set **uniform** for all elevators –Δk_m and Δn. This condition must be met to compare the operating modes and load levels of elevators.
5. The total number of $K_{m\Sigma}$ and N_Σ values and the number of values k_{Mi} and n_i, that fall within this range are calculated (I is the number of the range).
6. The frequency of values falling into this range is calculated:

$$p_{ki}= k_{Mi}/ K_{m\Sigma} \text{и} p_{ni}= n_i/N.$$

The sum of all the frequencies for each elevator must be equal to 1

Table 2

Primary processing of daily data for passenger elevator No. 1

(address: Kapustina street, 14: floors – 9, number of entrances – 2, total elevators – 4, including passenger elevators – 4, 2 in each entrance, the number of apartments – 36; the estimated number of residents served by this elevator – 108, maximum load capacity – 400 kg; observation period – from 07.07.2019 (from 22.00) to 08.07.2019 (to 22.00), i.e. only 24 hours, or 1440 minutes, or 86 400 seconds.)

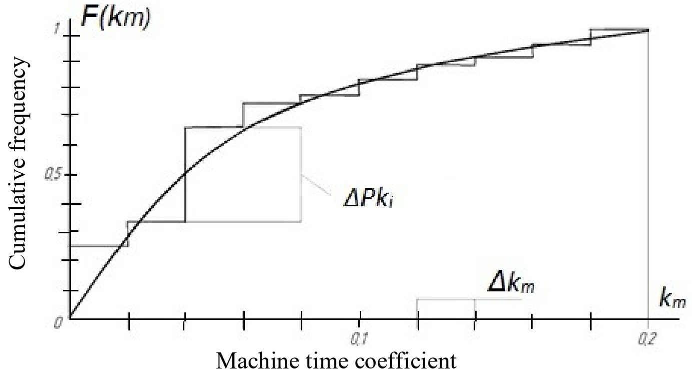
Characteristics of the elevator operating mode during 24 hours of daily operation				
Currenttime, hour.	Duration of the elevator's net machine operating time per hour, t_m, c	Coefficient of machine time of elevator operation during a given hour, $k_m= t_m/3600$	The number of starts is the main drive for this hour, $N_ч$	Specific number of starts during an hour of net machine time $n=N_ч/k_m$,1/час
Date: 07.07.2019				
Night mode				
22	208	0,057	14	246
23	143	0,040	8	200
Date: 08.07.2019				
00	103	0,029	6	207
01	0	0	0	0
02	39	0,011	4	364
03	0	0	0	0
04	0	0	0	0
05	0	0	0	0
06	46	0,013	8	615

Characteristics of the elevator operating mode during 24 hours of daily operation				
Currenttime, hour.	Duration of the elevator's net machine operating time per hour, t_m, c	Coefficient of machine time of elevator operation during a given hour, $k_m = t_m/3600$	The number of starts is the main drive for this hour, $N_ч$	Specific number of starts during an hour of net machine time $n=N_ч/k_m$, 1/час
Morning mode				
07	211	0,059	11	188
08	162	0,045	12	267
09	238	0,066	16	242
10	574	0,159	30	188
Day mode				
11	204	0,057	14	247
12	214	0,059	12	202
13	165	0,054	9	196
14	244	0,068	16	236
15	292	0,081	15	185
16	190	0,053	12	227
Evening mode				
17	267	0,074	14	189
18	217	0,060	16	265
19	423	0,112	24	204
20	432	0,12	31	258
21	438	0,122	29	238
Total: 24 hours of total time	4810 s. of net machine time during the day	0,0557 – average k_m per day	301 starts in 24 h., or 12.54 starts in an hour of total working time	n=3,75 starts./minute – average value n

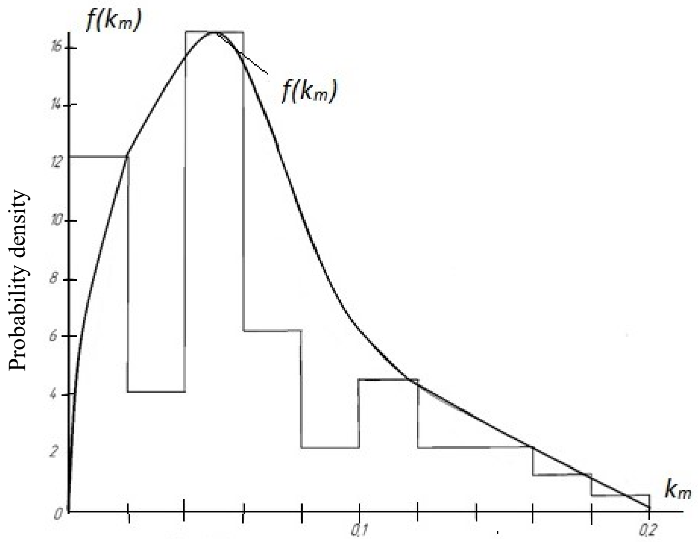
7. Based on item 6, a graph of accumulated frequencies for each elevator is constructed. These graphs are essentially experimental distribution functions for random variables k_m, N– $F_1(k_m)$ and $F_2(n)$ (fig. 6,a).

8. We calculate the density distribution values of K_m and N for each elevator —$f_1(k_m)$ and $f_2(n)$. To do this, in each range, the frequency increment (item 6) is divided by the range (item 4) —$f_{1i}(k_{mi})=\Delta p_{ki}/\Delta k_m$ and $f_{2i}(n_i)=\Delta p_{ni}/\Delta n$. The resulting value is put on the distribution density graph in the middle of the range (Fig. 6, b). For example, figures 6,a and 6,b show the calculation of the distribution density of the value K_m on the K_m=(0,04;0,06). The probability of a random variable K_m hitting this section is equal to the difference in the values of the distribution function (frequency) Δp_k=0,663-0,333=0,33 (fig.6,a). The probability density is equal to the ratio of Δp_k to the K_m change in the section ΔK_m=0,02, i.e. $f(k_m)$=0,33/0,02=16,5 (fig.6,б). Checking the correctness of constructing the functions $f_1(k_m)$ and $f_2(n)$ consists in estimating the area under the distribution density curve, which should be close to one.

2. The set of regular initial data for the group of elevator units. The selected set of observation objects — elevator units — can be characterized as sufficient, which is characterized by a combination of various factors that significantly affect the operating modes and equivalent loads (table 1 and fig. 1). Among the units accepted for monitoring are houses of various storeys (9 ... 24 floors), elevators of various load capacities and purposes (400...1000 kg). The estimated number of residents served by the elevator is also different. The observation period can also be considered sufficient, with all objects surveyed for one fixed period of time (more than 7 days of continuous monitoring).



a)



b)

Fig. 6. Construction of the distribution function $F(k_m)$ (a) and the probability density $f(k_m)$ (b) on the example of the machine time coefficient K_m

This allowed us to obtain a representative sample of random elevator performance indicators, the main purpose of which is to serve as a basis for comparing real indicators with the results of simulation.

The data obtained from regular monitoring of the operating modes of elevator units can be considered a representative sample both in terms of volume and the number of factors considered. For each of the elevators, the volume of continuous observations is more than 180 hours with a record of the net operating time and the number of starts during each hour.

The necessary number of observations was estimated using the student's distribution [10]. To determine the required number of observations, the following ratio is valid:

$$N_{\text{набл}} \geq \left[\frac{K_\sigma f(\beta)}{0_{\text{ш}}}\right]^2,$$

whereK_σ – the coefficient of variation of experimental data, i.e. the ratio of the average square deviation to the average value of a random variable;

$f(\beta)$ – a parameter in the Student's distribution that depends on the accepted confidence level β;

$O_{\text{ш}}$ – an acceptable error in determining the average value of a random variable (by the level of responsibility of the process).

The calculated data for the data on the average values of the elevator machine operating time coefficient and the number of main drive starts based on the results of regular monitoring are shown in table 3.

Table 3

Estimation of the required number of daily observations

Indicator of the elevator operating mode	Averageval ue	Meansquare deviation	Coefficient of variation, K_σ	Confidence probability, β	Parameter in the Student's distribution	Acceptable error in determining the average value	Required number of observations per day
Specific number of MD starts, 1/min.	3,75	1,16	0,31	0,9	1,66	0,1	26
	3,75	1,16	0,31	0,9	1,66	0,12	19
Coefficiento fmachinetim e	0,15	0,05	0,33	0,9	1,66	0,1	29
	0,15	0,05	0,33	0,9	1,66	0,12	21

The estimates of the required number of daily observations to obtain a sample with an error of no more than 12% at a confidence level of 0.9 indicate that measurements of regime indicators once per hour (24 measurements per day) can be considered sufficient.

The main results of processing the primary monitoring data for each elevator unit were the average values of the machine time coefficient k_{mcp} and the number of MD starts per minute of net machine time N_{cp}, as well as the functional characteristics of these random variables — the distribution functions $F(k_m)$, $F(n)$ and the probability density $f(k_m)$, $f(n)$. The main results are presented in a compact form in table 4 and in figures 7 and 8.

Table 4

Average values of the modes of operation of the elevators

Elevator numbers according to table 1	1	2	3	4	5	6	7
Machinetimecoeffi cient	0,190	0,089	0,149	0,056	0,063	0,040	0,145
Number of starts, 1/min	2,45	2,13	1,90	3,43	2,75	2,86	1,95
Elevator numbers according to table 1	8	9	10	11	12	13	14
Machinetimecoef-ficient	0,065	0,088	0,107	0,080	0,122	0,090	0,166
Numberofstarts, 1/min	1,83	3,08	2,25	1,89	1,90	1,47	1,87

For elevator15: k_{mcp}=0,186; N_{cp}=2,0

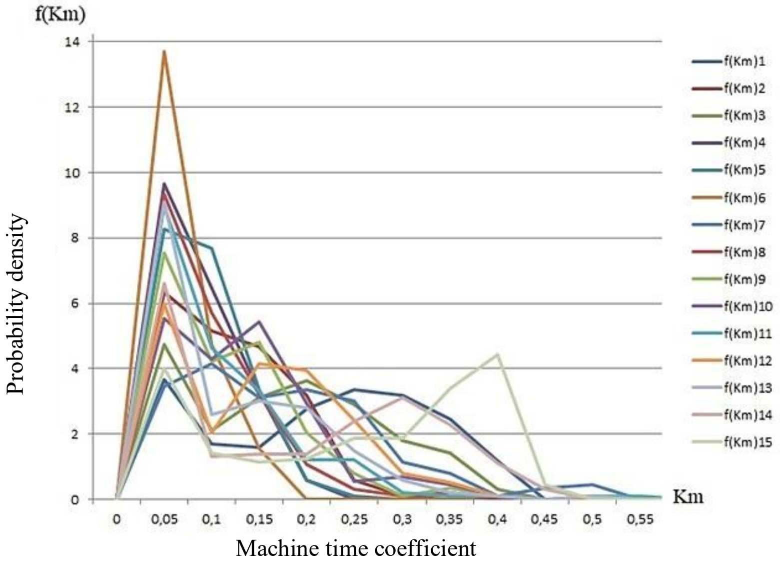


Fig. 7. Probability density of the machine time coefficient

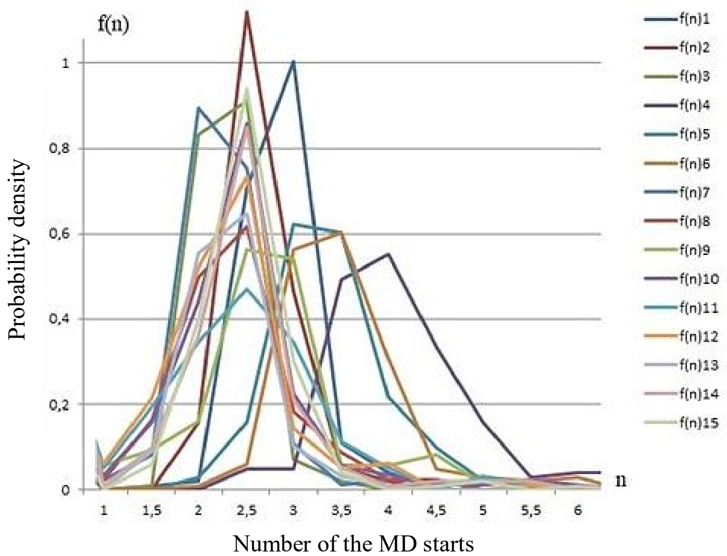


Fig. 8. Probability density of the specific number of starts

3.Assessment of the influence of the most important factors on the calculated load of power elements of elevator units. The analysis of monitoring data and their processing show:

— the main indicators of the operating mode of the elevator MD vary widely: the coefficient of machine time — five times, from 0,04 to 0,19, the number of inclusions per minute of net machine time — 1,87 times, from 1,83 to 3,43;

— the machine time coefficient objectively characterizes the net time when all elevator elements are in working condition, the values of this coefficient for most units are at a low level (0,05...0,12), this indicates a significant underloading of the main drive and other components;

— the specific number of starts determines the frequency of application of dynamic loads on the drive, ropes, cab structure and other components, the characteristic value of the number of starts from 2 to 3 per minute of net machine time, in terms of the hourly frequency of starts, this will be 120 ... 180 starts, which is quite acceptable for the engines used;

— a stable correlation between k_m and n indicators was not found, although the trend of increasing the machine time coefficient with a decrease in the specific number of starts can be traced, 9 lifts out of 15 taken for monitoring fit into this relationship:

n	1,45	1,90	1,90	1,95	2,25	2,75	2,17	2,86	3,43
k_m	1,95	0,149	0,122	0,0,146	0,107	0,063	0,089	0,04	0,056

— each lift is characterized, usually individual a pair of values of k_m and n, the value of which depends on a number of factors: the number of storeys of the building, number of residents for the elevator, elevator load-carrying capacity, the average time between two adjacent requests to use the elevator and some other;

— with the increase in the number of storeys of the building, the coefficient of machine time increases, while, as a rule, the specific number of starts does not increase, this is due to the fact that the average length of the elevator movement during the cycle of use increases, and the number of intermediate stops remains at the same level;

— the main influence on the load indicators of the elevator is the number of residents who actually use the elevator, as shown by the analysis, the real number of users may differ significantly from the estimated number of registered persons in a given entrance or building; for example, when comparing the indicators of two elevators with different estimated number of residents (table. 4) we have:

— Elevator no. 1 (68 Orbitalnaya street): floors — 9, residents — 513, k_m/n=0,19/2,45;

— Elevator no. 15 (30 Panova street): floors — 24, residents — 630; k_m/n=0,186/2,0.

Conclusion. The performed research allowed us to obtain regular observations of the main regularities of the formation of loading modes of passenger elevators power elements on the basis of statistical processing of data.
A significant influence of random factors that form the main indicators of elevator loading — the coefficient of machine time and the specific number of starts.

The main purpose of the obtained results is to be able to use them to assess the adequacy of the formation of loading modes in the simulation of passenger elevators in comparison with real indicators.

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Contribution of the authors

G.Sh. Khazanovich – development of research methods and statistical processing of the initial data, final analysis of the results of the study, conclusion. D.S. Apryshkin – processing of the original data observations, construction of the main dependencies, graphic design, evaluation of the influence of the most important factors on the calculated load of the load-bearing elements of elevator installations.

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Mathematical analysis and forecasting of the dynamics of air pollution by stationary sources in the Russian Federation

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Introduction. The article considers the dynamics of air pollution by stationary sources in the Russian Federation from 1998 to 2016. Harmful emissions into the atmosphere cause great harm to all living organisms. As a result, the life expectancy of the population is significantly reduced. Therefore, the assessment of pollution volumes and subsequent measures for the protection of atmospheric air are priority tasks of our time.
Problem statement. The objectives of the study are to analyze the dynamics of pollution, build a mathematical model of this process, and implement a forecast for a five-year period.
Theoretical part. Data for the work is taken from the official statistical book. Microsoft Excel and StatSoftStatistica computer technologies are used for calculations.
Conclusion. Based on the analysis, an adequate mathematical model is constructed, which may be of interest for predicting the anthropogenic impact on the environment.

Keywords: atmospheric pollution, mathematical model, least squares method, forecasting.

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Introduction. Air pollution causes great harm not only to living organisms, but also to the hydrosphere, soil and vegetation cover, buildings, structures and other objects. People who live in places with polluted air often have diseases such as allergies, cancer, and various lung diseases. As a result, life expectancy is significantly reduced. Therefore, the protection of atmospheric air is one of the priorities of our time.

Main sources of atmospheric pollution in Russia are: industry, transport, utilities and agriculture. The level of air pollution depends, as a rule, on the degree of urbanization and industrial development of the territory.

The paper considers the amount of harmful substances (hereinafter — pollution) released by stationary sources into the atmosphere in 1998-2016. The task of the authors is to analyze the dynamics of changes in pollution, to build a mathematical model of this process and to forecast it for a five-year period. The source data is taken from the book "Russia in numbers" [1].

Methodology. The values of atmospheric air pollution are presented in Table 1, and Fig. 1 shows their graphical representation.

Table 1

Air pollution values in the Russian Federation

Year	Pollution, million tons	Year	Pollution, milliontons
1998	18,7	2008	20,1
1999	18,5	2009	19
2000	18,8	2010	19,1
2001	19,1	2011	19,2
2002	19,5	2012	19,6
2003	19,8	2013	18,4
2004	20,5	2014	17,5
2005	20,4	2015	17,3
2006	20,6	2016	17,3
2007	20,6	-	-

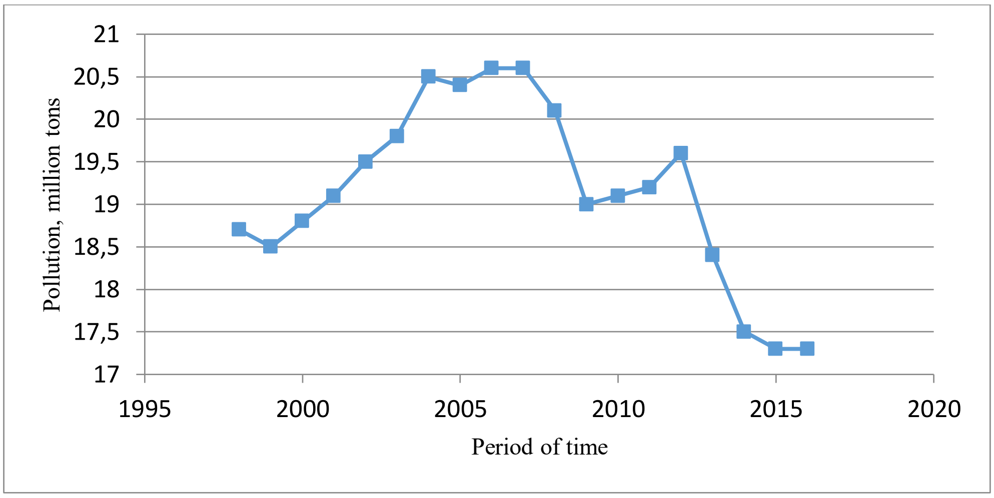

Fig. 1. Dynamics of changes in air pollution in the Russian Federation

The initial data show fluctuations in pollution against the downward trend, so the model dependence of pollution on time is a linear combination of monotonically decreasing and oscillatory functions. The monotonically decreasing function is an exponent, and the oscillating function is a sinusoid [2-4]:

$$\bar{X} = A + Be^{-C(t-1998)} + D \cdot \sin\left[\frac{2\pi}{E}(t+F)\right], \quad (1)$$

where$\bar{X}$ — the mathematical expectation of the pollution value; t — the year; A, B, C, D, E, F — the parameters of the exponential-harmonic function.

Since there are many adjustable parameters in function (1): three parameters in the exponent (constant, amplitude, and time) and three parameters in the sine wave (amplitude, frequency, and shift), and the initial data is small, the process of model identification was divided into two stages.

At the first stage, ignoring the fluctuations, the exponential dependence was identified:

$$\bar{Y} = A + Be^{-C(t-1998)}.$$

The coefficients A, B and C are found by solving the optimization problem:

$$\sum_i (Y_i - Y(t_i))^2 \to min, \quad (2)$$

wheret_i — the value of the argument (time); Y_i— the actual value of pollution:

$$Y(t_i) = A + Be^{-C(t_i-1998)}.$$

At the second stage the oscillatory part is considered:

$$\bar{Z} = D \cdot sin\left[\frac{2\pi}{E}(t+F)\right].$$

The coefficients D, E and F are found by solving the optimization problem:

$$\sum_i \left(Z(t_i) - \left(Y_i - Y(t_i)\right)\right)^2 \to min, \quad (3)$$

wheret_i — the value of the argument (time):

$$Z(t_i) = D \cdot sin\left[\frac{2\pi}{E}(t_i+F)\right];$$

Y_i– the actual value of pollution

$$Y(t_i) = A + Be^{-C(t_i-1998)}.$$

Results. To find unknown coefficients, we used the functions of the *Microsoft Excel* solution search package [5-7]. As a result of solving the optimization problem (2) by the least squares method [8], the coefficients were found: A = 15,4; B = 4,378; C = 0,017. As a result of solving the optimization problem (3), the coefficients were found: D = 1,253; E = 19,287; F = -2001,84.

The final type of the dependency (1):

$$\bar{X} = 15{,}4 + 4{,}378 \cdot e^{-0{,}017(t-1998)} + 1{,}253 \cdot sin\left[\frac{2\pi}{19{,}287}(t-2001{,}84)\right]. \quad (4)$$

Table 2 shows [9] the characteristics obtained from the model (4).

Table 2

Characteristicsof themodel

Year	Actual pollution, million tons	Estimated pollution, milliontons	Absolutedeviation, milliontons	Relativedeviation, %	Square of the relative deviations, %
1998	18,7	18,587	0,113	0,603	0,363
1999	18,5	18,700	0,200	1,083	1,173
2000	18,8	18,920	0,120	0,639	0,408
2001	19,1	19,216	0,116	0,605	0,366
2002	19,5	19,548	0,048	0,247	0,061
2003	19,8	19,875	0,075	0,379	0,144
2004	20,5	20,155	0,345	1,684	2,836
2005	20,4	20,350	0,050	0,243	0,059
2006	20,6	20,434	0,166	0,805	0,648
2007	20,6	20,390	0,210	1,017	1,035
2008	20,1	20,217	0,117	0,581	0,337
2009	19	19,925	0,925	4,866	23,678
2010	19,1	19,538	0,438	2,293	5,258
2011	19,2	19,091	0,109	0,567	0,322
2012	19,6	18,624	0,976	4,977	24,774
2013	18,4	18,181	0,219	1,191	1,419
2014	17,5	17,801	0,301	1,718	2,951
2015	17,3	17,518	0,218	1,259	1,585
2016	17,3	17,356	0,056	0,323	0,105

The following indicators are calculated:

- the correlation coefficient is 0,936;
- the average value of the absolute deviation is 0,253 million tons;
- the average value of the relative deviation is 1,320 %;
- the maximum relative deviation is 4,977 %;
- the standard deviation is 1,885 %;
- the model's adequacy is 1,889 %.

Fig. 2 shows the atmospheric pollution values obtained from the model (4).

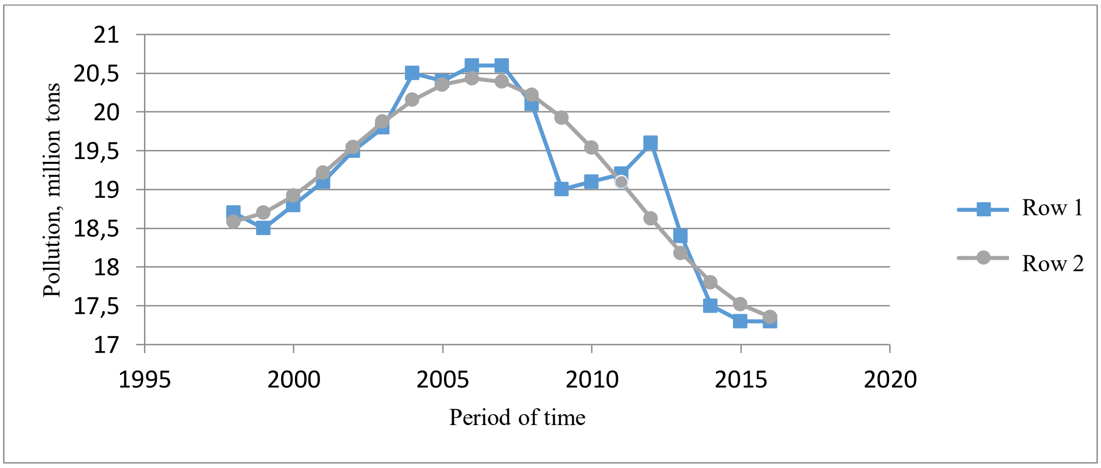

Fig. 2. Dynamics of changes in the atmospheric pollution in the Russian Federation:
row 1 — actual data; row 2 — calculated data

The forecast for the period 2017-2021 was also obtained using formula (4) [10]. Table 3 presents the forecast results.

Table 3

Comparison of actual and predicted data on pollution

Year	Real value, milliontons	Predictedvalue, milliontons
2017	17,5	17,326
2018	17,1	17,426
2019	-	17,639
2020	-	17,937
2021	-	18,284

The forecast error is 0,994 % for 2017, and for 2018 it is 1,906 %.

Conclusion:

- the dynamics of air pollution from stationary sources in the Russian Federation in 1998-2016 is analyzed;
- a relationship was found that reflects the change in the amount of harmful emissions over the specified period;
- an adequate mathematical model has been constructed that may be of interest for predicting anthropogenic impacts on the environment and can be used as one of the tools for developing alternative models for such forecasting;
- the forecast of the dynamics of changes in atmospheric pollution in the Russian Federation for a five-year period has been implemented.

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E. S. Gorbacheva — statement of the problem, collection and analysis of literature, research methodology, derivation of the mathematical dependence, identification model and calculation of its coefficients, checking the adequacy of mathematical models, receiving a forecast and verification of data errors, text editing, literary analysis, preparation of the manuscript; I.M. Peshkhoev — scientific supervision, formulation of the basic concept of the study and structure of the article.